Ocean Thermal Energy Conversion (OTEC)

Program Summary
October 1976

ERDA 76-142

Division of Solar Energy

Energy Research & Development Administration
Washington, D.C. 20545

For sale by the Superintendent of Documents, U.S. Government Printing Office Washington, D.C. 20402 - Price $1.70

There is a minimum charge of $1.00 for each mail order.

Ocean Thermal Energy Conversion (OTEC)

Program Summary
October 1976

ERDA 76-142
DISTRIBUTION CATEGORY UC-64

Division of Solar Energy

Energy Research & Development Administration
Washington, D.C. 20545

FOREWORD

Ocean Thermal Energy Conversion (OTEC) is one of six solar technologies that constituted the original U.S. solar energy program. Those technologies were selected by the National Science Foundation (NSF) Research Applied to National Needs (RANN) program as being options that could each potentially provide a substantial energy contribution to the nation. When the U.S. Energy Research and Development Administration (ERDA) was established on January 19, 1975, the lead role in solar energy was transferred from NSF to ERDA.

The history of the OTEC program in the United States is described in numerous reports and publications, many of which are referenced in the Bibliography in this Program Summary, which was prepared by the Ocean Systems Branch, Division of Solar Energy, Energy Research and Development Administration, Washington, D.C. 20545. Three public OTEC workshops have been held, beginning in 1973. The first OTEC Workshop was organized by Carnegie-Mellon University and held in Pittsburgh, Pennsylvania on June 27 and 28, 1973. The second was organized by the University of Miami and held in Washington, D.C. on September 26 to 28, 1974. The third was organized by the Applied Physics Laboratory of Johns Hopkins University and held in Houston, Texas, May 8 to 10, 1975. Proceedings of each of these OTEC workshops have been published, and contain the papers presented, transcriptions of discussion, and reports of Working Groups. In addition to the public workshops, various specialized workshops on special facets of the OTEC program have been held in the past three years.

Other renewable ocean energy resources (waves, currents, tides, and salinity gradients) are also of interest to ERDA. Additional energy resources that could be utilized at sea include winds over the ocean and biomass production. The Ocean Systems Branch is conducting technology assessments of the wave, salinity gradient, and ocean current options. Proceedings of a recent ERDA-sponsored Workshop on Wave and Salinity Gradient Energy Conversion may be obtained through TIC/NTIS (cf. page 88).

The OTEC program contains areas of interest to various Federal agencies, some of whom have participated in funding OTEC projects and some who have participated in planning and managing the OTEC program. Forthcoming activities in the OTEC program are summarized in the Program Summary commencing on page 1. OTEC funding by ERDA and NSF for Fiscal Years 1972 through 1976 is summarized on page 12. OTEC projects that are presently being funded by Federal agencies, or that are already completed but are still of current interest, are summarized commencing on page 13.

CONTENTS

OCEAN THERMAL ENERGY CONVERSION PROGRAM SUMMARY

1 Introduction

Ocean Thermal Energy Conversion (OTEC) offers the nation a new and renewable source of base-load electric power. Estimates of ocean thermal energy contributions are forecast (Reference 1) as at least 20 GWe by the year 2000.

The principal applications of OTEC technology are the production of electrical power and energy-intensive products (chemicals, fuels, and metals). Additional applications include the promotion of aquaculture through the supply of nutrients (phosphates and nitrates) contained in the cold ocean water, and the production of fresh water. Studies and proposals by private industries (Reference 2) indicate that OTEC power plants in the 100 to 1000 MWe range have commercial applications for electric transmission to shore and for chemical process applications.

An OTEC plant can be operated in a "closed" or "open" cycle. In the closed cycle, a working fluid such as ammonia or propane is utilized. In the open cycle, ocean water is used as the working fluid.

The greater probability of achieving OTEC performance goals with a closed cycle system led to its selection as the baseline power system for initial demonstration. Although major emphasis is being given to the closed cycle system, the open cycle system is being evaluated for possible second generation application, as warranted by technology developments (Reference 2). Similarly, ammonia was selected as the closed cycle working fluid that would produce energy most economically (Reference 2).

The heat exchanger component of the OTEC power plant is the pacing item in achieving economic viability. Biofouling and corrosion can significantly impact the overall performance of the heat exchangers. These factors force an early ocean testing of heat exchangers. Several alternative heat exchanger concepts have been proposed, in both tube and shell and panel configurations. Tube and shell configurations have been selected for initial offshore testing on the basis of prior industrial background and experience.

Concurrently, successive generations of OTEC heat exchangers are being developed, leading to their early ocean testing. The testing program will provide performance verification and evaluation of the control and effects of biofouling and corrosion. It also includes a pilot power plant to obtain data on the overall power system.

Based upon an evaluation of tradeoffs between ocean test platforms and land-based test facilities for early testing of OTEC components and systems, the former approach has been selected. This conclusion resulted from cost, benefit and schedule considerations. A land-based Engineering Test Facility is still being considered. It may be implemented if the government's role in OTEC development requires extensive testing of a large number of heat exchanger configurations. Critical programmatic issues that have been clarified and resolved are summarized in Table 1.

2 Objectives and Goals

Demonstrate by 1984 the operation and performance of an ocean thermal power plant having a sufficiently advanced heat exchanger design to project economic viability.

Develop economically viable heat exchanger concepts through research and development, bench scale (core) tests, ocean tests of large components, and pilot power plants on large floating test facilities.

Perform mission analysis and hull configuration analysis for specific applications to define demonstration and commercial configuration(s).

Determine the impact of biofouling and corrosion on long term performance capability of OTEC options.

Define test site environmental characteristics such as temperature and current profiles, wind and wave forces, biota, etc.

Assess possible environmental impacts of OTEC on ocean temperatures, salinity, biota, local climate.

Evaluate industrial processes yielding energy-intensive products to determine performance and reliability in an ocean environment.

Adapt and develop the technology of submarine electrical cables and other submarine umbilicals.

3 Program Approach

Figure 1 illustrates the task flow between the three interacting program functions. The subtask elements of the program are shown within each box.

The general approach is through technology development of critical components, demonstration of an economically viable Ocean Thermal system, research and development of materials, evaluation of ocean environmental factors and assessments of potential markets to minimize the uncertainties in ocean thermal commercialization. Table 2 indicates the top-level programmatic issues to be clarified or resolved.

TABLE 1. ISSUES CLARIFIED OR RESOLVED TO DATE – OTEC PROGRAM

Issue	Program Impact
The resource potential of ocean thermal energy has been established as substantial, and abundant sites are available	OTEC clearly satisfies ERDA requirements for providing a substantial source of energy for supplying U.S. energy needs of electricity and energy-intensive products
100 MWe Ocean Thermal System module size of 25 to 40 MWe reference system for electrical application	Selection of a 100 MWe demonstration plant size (1984 time frame) and of a 25 MWe power plant module (1983 time frame)
Base-load application	Energy utilization and mission analysis studies oriented toward base-load options (unlike other solar-electric applications)
Closed cycle power plant with ammonia as the working fluid	The open cycle option and on other closed cycle working fluids are being examined as exploratory technology under strategic alternatives category. Review Dec. 77.
Emphasis on shell-tube and tube heat exchangers for initial core tests and early ocean testing	Permits development of heat exchangers that are technologically closest to current state of the art, hence most likely to operate successfully
"Early" ocean test platforms	Provide early component and system testing, allowing an earlier opportunity for testing large-size heat exchangers (compared to land-based facilities)
Pilot floating power plant of 5 MWe in a conventional hull (no OTEC requirement was established for a specialized OTEC hull at this stage)	Provide for an early system test to obtain performance verification and valuable operational information

TABLE 2. PROGRAMMATIC ISSUES TO BE RESOLVED – OTEC PROGRAM

Issue	Program Phase
Product mix, marketability, thermal resource and siting assessments	Strategy and Definition Planning
Technical and economic viability of OTEC heat exchangers	Engineering Development and Demonstration
	Technology Base
Impact of biofouling and corrosion on system performance	Engineering Development and Demonstration
	Technology Base
Interest of utility and industrial user groups	Commercialization
Hull/structure platform configuration	Strategy and Definition Planning
	Engineering Development and Demonstration
Evaluate requirement for a land-based Engineering Test Facility	Strategy and Definition Planning
Evaluate potential applications of alternate cycles and demonstrate critical feasibility	Strategy and Definition Planning
	Technology Base
Possible impacts on biota, thermocline, and climate	Strategy and Definition Planning

3.1 Strategy and Definition Planning

Mission analyses now underway are identifying and evaluating commercial ventures using OTEC technology, and determining locations where and conditions under which OTEC applications are competitive in the marketplace. The impacts of current and advanced technology, as well as legal, political, institutional and environmental factors are being addressed. Product mix, site-specific economics, and the definition of appropriate commercial power plant sizes are being examined.

Based on these and other related studies, system and subsystem design and environmental specifications and performance will be defined. These will depend (1) on the nature and location of specific missions (commercial ventures); (2) on the selection of construction, deployment, operation, maintenance and repair policies and procedures; (3) on component groupings into subsystems that safeguard health, safety, welfare and convenience of the operating crew, special maintenance or repair personnel, and visitors; and (4) on designs which provide a spare parts policy which is both economic and prudent.

Environmental studies employing fluid dynamical computer modeling began in FY 75 and laboratory modeling studies have recently commenced. Further work on other OTEC environmental questions will be funded in FY 1977.

Ocean engineering studies are underway to select appropriate hull configurations, a major cost component of OTEC systems. Important criteria in this selection are (1) the most universal configuration, i.e., one compatible with the maximum number of sites, (2) if it can be built within existing U.S. facilities without major modification and (3) the most economic approach and performance in all environmental conditions. Studies on hull constructibility and siting are being performed in FY 77 and FY 78 to provide data for this evaluation.

A land-based Engineering Test Facility (ETF) is being considered as a program option. It would initially be used for component testing, and subsequently for subsystem testing. Results of a preliminary tradeoff

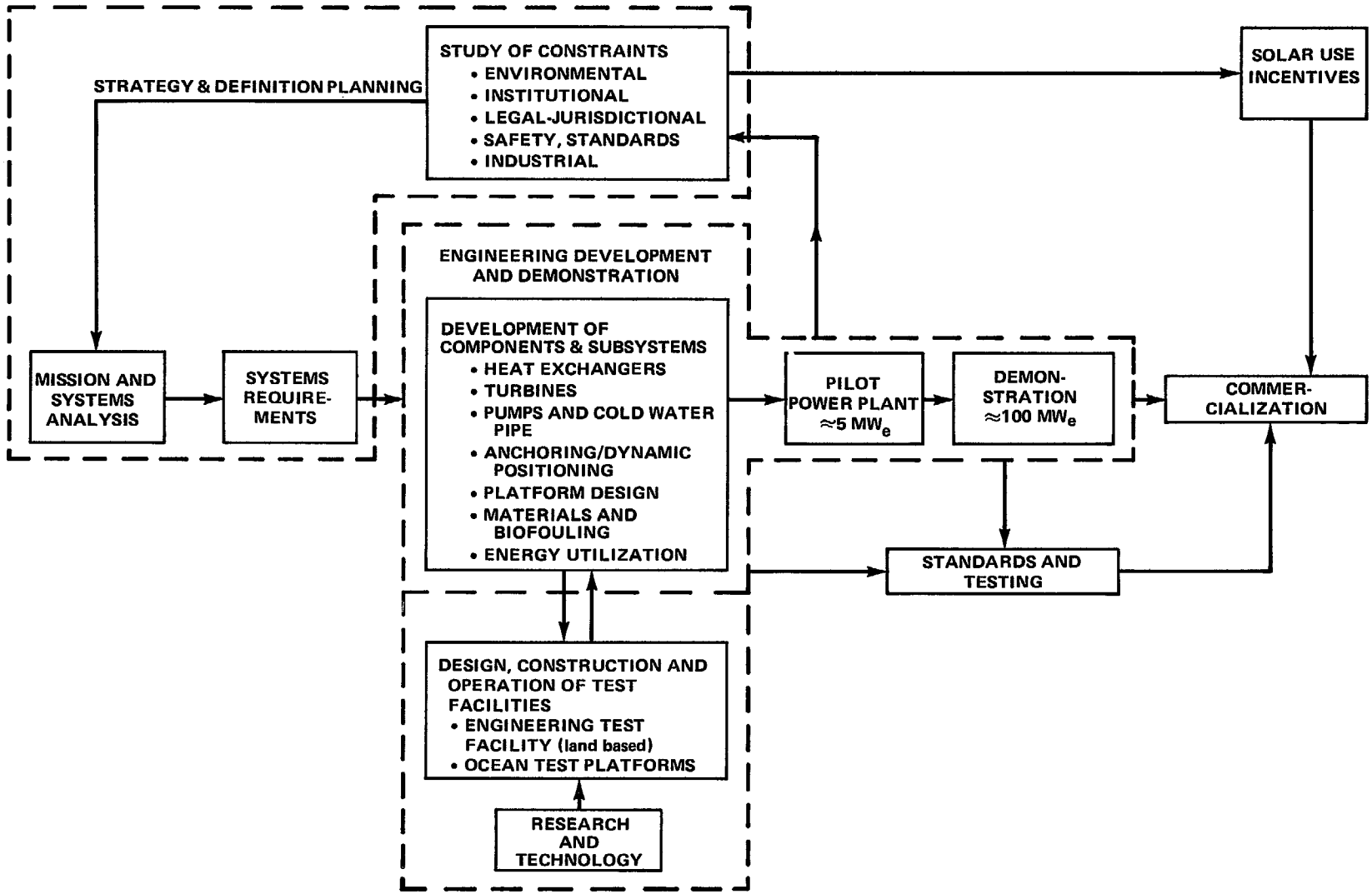


Figure 1—Ocean Thermal Energy Program Structure

study comparing a 5 MWe ocean-based facility and a 5 MWe land-based facility indicate that the land-based facility is more costly, but more flexible in its use.

Milestones relative to efforts in the Strategy and Planning phase of the program include:

FY 1977 – Resolution of the marketability of OTEC electricity and energy-intensive products, including product-mix for viable industrial and electrical applications

FY 1977 – Decision on the need for a land based test facility.

FY 1978 – Resolution of specialized OTEC hull requirements for the above applications, consistent with packaging of OTEC power cycle and energy conversion systems

– Determine siting for demonstrations and OTEC utilization

– Select test program and systems integration contractors

3.2 Engineering Development and Demonstration

For the baseline program development option considered, the Ocean Thermal Program has three physical components, (a) the power system (closed cycle), (b) the platform (choice of six basic shapes), and (c) the product manufacturing and distribution system (electrical cable or ocean industrial complex). The associated engineering development and demonstration milestones are given in Figure 2.

Table 3 indicates the degree of development required for OTEC components and subsystems. The heat exchanger elements require significant conceptual definition, research and development of configurations. The heat exchanger represents about 55% of the cost of the system. At the next level, several subsystems require some development testing of specific design configurations but do not require exploratory evaluations. Other subsystems can be designed without significant test requirements.

Power Plant

The heat exchanger is the pacing development item for an economically viable ocean thermal system. Several alternate shell and tube, and tube (horizontal tube thin film, horizontal tube nucleate boiling, vertical tube falling film and trombone) configurations have been proposed, as well as panel concepts. The economics of the heat exchanger is intimately related to ammonia-side and water-side heat transfer enhancement, producibility of the heat exchanger, and the material from which it is made. Current smooth-tube technology will produce overall values of 300 to 400 BTU/hr sq. ft. deg. F. Several surface enhancement and notching or fluting techniques are considered capable of more than doubling this rate. The initial cost of aluminum material is one-third that of titanium, but corrosion effects on life expectancy of the heat exchanger remain a serious question. The impact of biofouling on the maintenance of the OTEC heat exchanger is of equal importance to the system economics.

TABLE 3. OTEC HARDWARE DEVELOPMENT REQUIREMENTS

Category	Component/Subsystem
1. Requires extensive research and technology testing	Evaporator Condenser Biofouling and Corrosion
2. Requires subsystem development testing	Turbine Cold Water Pipe Mooring/Dynamic Positioning Power Cable
3. Application engineering required	Working Fluid (including charging and storage) Generator Cold Water Pump Warm Water Pump Working Fluid Pump Debris Control and Screens Hull and Structure Electrical Switchgear Control and Instrumentation
4. Standard	Piping, Valves and Tanks Warm Water Duct Support Systems (including Diesel generator)

Figure 3 shows the milestones of the heat exchanger development approach. Initial single or multitube laboratory tests are conducted to determine the heat transfer performance of single tube features (i.e., surface enhancement, grooves, flutes, inserts, etc.). Core or bench testing will then be performed on configurations of 1600 one-inch tubes (approximately 8' long for the bundle diameter of 4'). The purpose of the tests will be to determine the overall heat transfer performance in a complicated geometric array. In this arrangement it is intended to assess the impact of vapor and liquid interactions on heat transfer performance. Other complicating performance phenomena, such as uneven flow over the face of a large heat exchanger, will be evaluated by hydraulic modeling studies. It is anticipated on the basis of the heat exchanger bench tests, cleaning studies, and hydraulic modeling studies that the data can be accumulated in October 1977 for a programmatic decision point that can be reached in December of 1977. However, other major uncertainties still exist such as the cost of manufacturing large heat exchangers, geometric effects on local flow conditions, biofouling and corrosion.

To assess these effects in an ocean environment as early as possible, an early 1 MWe (40 MWt) component

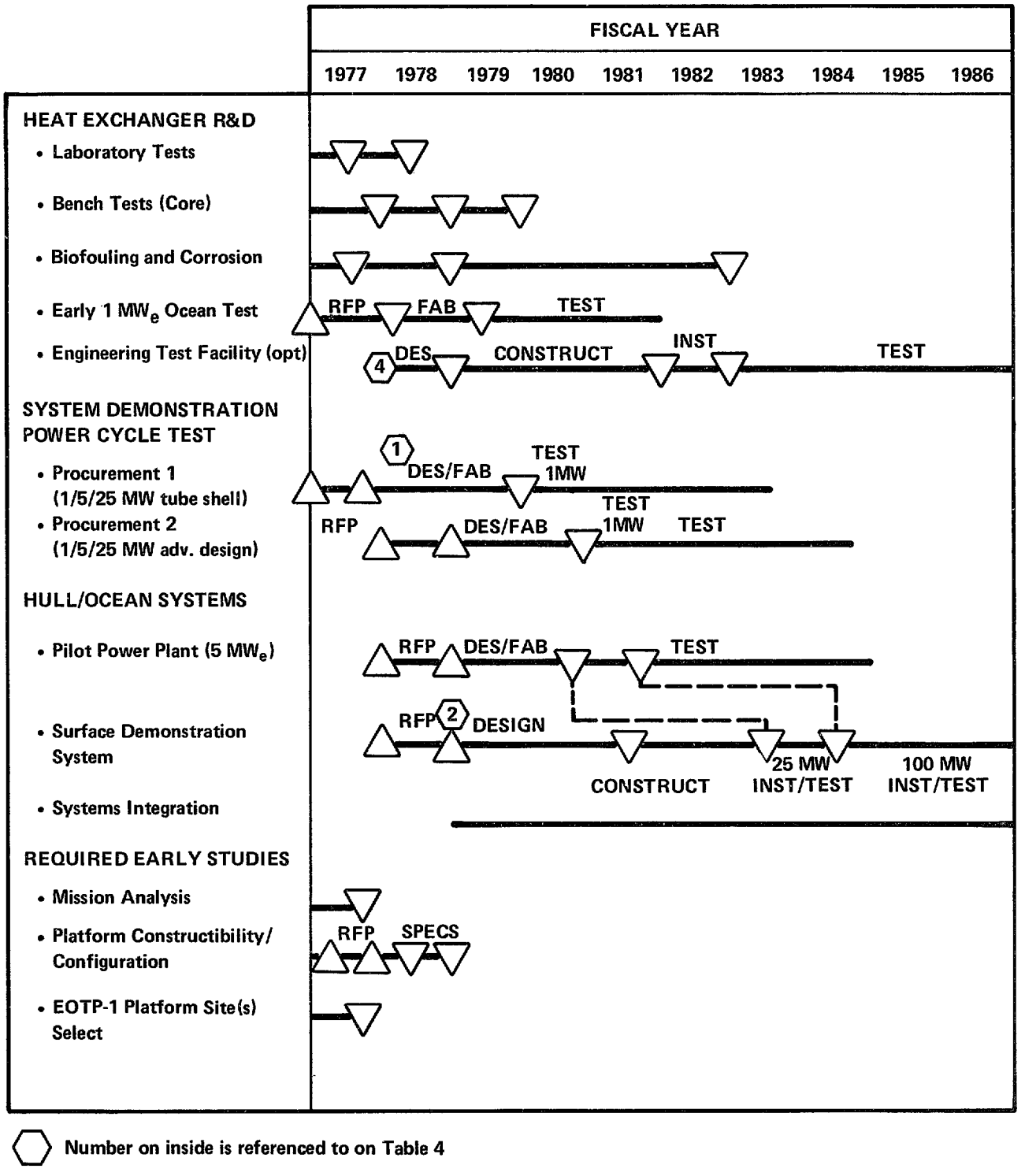
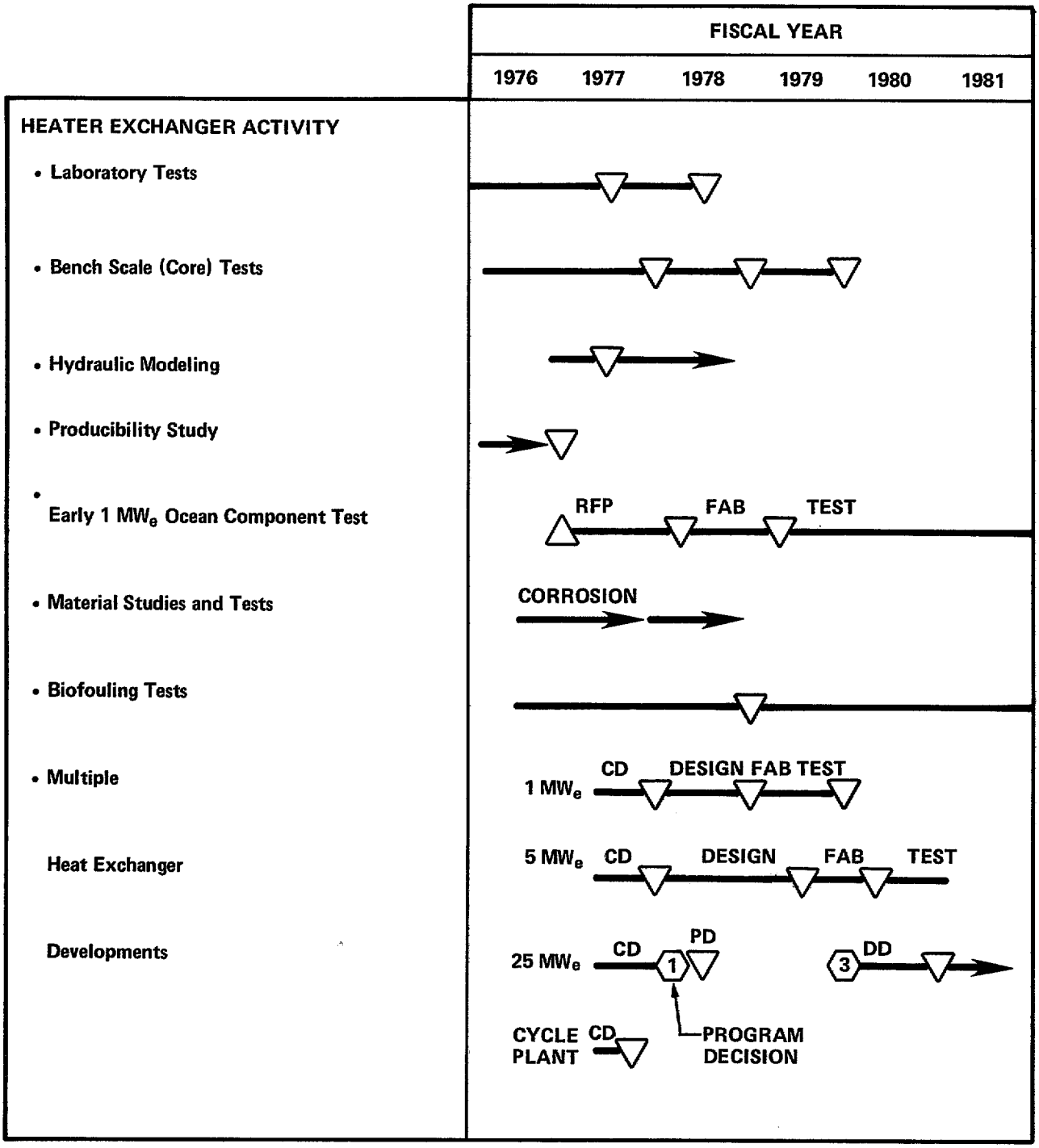


Figure 2—Ocean Thermal Program Engineering Development and Demonstration Milestones



⬡ Number inside is referenced to on Table 4
CD — Conceptual design
PD — Preliminary design
DD — Definitive design

Figure 3—Heat Exchanger Milestones

test platform is planned for ocean tests starting in mid FY 1979. Heat exchangers for the initial 1 MWe tests will be of conservative shell and tube design.

Biofouling and corrosion studies, laboratory tests and ocean surveys of potential sites will continue through 1980, and provide early information to support the first (1977) and second (1978) generation technology, plus the 25 MWe programmatic decision (1979), and subsequent heat exchanger (alternative) decisions. Meanwhile, the cost reduction potential of advanced technology concepts will be pursued. These concepts include hybrid cycles, alternative working fluids, direct contact heat exchangers, and hydraulic power cycles.

As has been mentioned, there are several candidate heat exchanger configurations, tube geometries and materials. The program plan seeks to compare these approaches in October 1977 and again review additional candidates in October 1978. It is planned to hold a competition among consortia of organizations to provide conceptual heat exchanger design definition in October 1977. The resulting candidate design studies will be incrementally funded, but will permit the option to carry a successful 25 MWe heat exchanger design approach through a sequence of tests, including a 1 MWe component test, a 5 MWe pilot power plant, and finally a 25 MWe module. (Each module size is considered nominal and may change somewhat on the basis of future mission and system studies and test requirements.)

In October 1977, one or two concepts may be carried beyond conceptual design. Preliminary design of the 25 MWe module will establish design constraints for the platform design. Twenty-five MWe module detailed design will start after the 1 MWe test article has been tested for three months. This will occur about one year after the early 1 MWe heat exchanger component tests (FY 79). Alternative heat exchanger concepts will be tested in system configuration in 1978. Production cost studies will be performed for the most promising candidates in 1979. This could lead to procurement of a 25 MWe module based on this advanced technology.

The ammonia-turbine research areas include selection of materials for blades, selection of noncorrosive materials and design for seals, and demonstration of bearing life. The lead time for procurement of an ammonia-turbine, with an estimated maximum efficiency of 85/90 percent, is three to four years. Turbine procurement to support a 25 MWe module test (1983) will be initiated in FY 1979.

Hull/Platform

Geared to the success of the heat exchanger program will be the design and development of a platform suitable for OTEC demonstration. Most of the ocean engineering elements of this platform are considered as either standard, or requiring only application engineering. Several elements that will require analysis and subsystem development testing are:

- Hull/structure
- Cold water pipe
- Mooring/positioning
- Electrical cable

Hull shapes being considered include: ship, spar, custom, semisubmersible, surface, and disk. A prototype hull/structural subsystem is not required for the 1 MWe and 5 MWe ocean test platforms, since existing marine structures can satisfy these testing requirements. The first specialized OTEC hull/structure will be required for the OTEC 25 MWe power module.

Key features of the cold-water pipe to be considered are: (1) size of the pipe and fittings, (2) deployment, (3) optimum matching of pump and pipe, (4) reactions to forces and motions applied by the hull and the ocean environment, (5) effects of basic gravity and buoyancy forces, and (6) diagnostic instrumentation.

Analysis of these items will require a hydraulic design of the entire cooling water system, a hydrodynamic analysis of the pipe, load analysis and structural design. The first OTEC cold-water pipes will be designed for the initial 1 MWe and 5 MWe ocean test platforms.

Station keeping is accomplished through mooring or dynamic positioning. Mooring options include use of single or multiple attachment points, and the dynamic positioning issue includes power transmission. Current studies are developing mooring concepts and conducting trade-off analyses for a range of hull shapes and over a range of site conditions. An approach will be selected by FY 78.

Present assessments of the OTEC application indicate that for the offshore situation the OTEC submarine cable will be high-voltage DC cable with conversion subsystems at each terminal. Single or multiple submarine cables must be capable of transmitting in the 10 to 500 MWe range. The state of practice (1976) in DC transmission is 250 KVDC, 250 MWe over distances up to 80 miles, at depths not exceeding a few thousand feet, between stationary terminals (Reference 5). Submarine cable development for OTEC will be initiated in FY 77 through a competitive procurement.

3.3 Technology Base

Research and Technology

Research and technology activities are underway in the areas of heat transfer technology (physics of evaporation, condensation and heat transfer at low temperature differences) and biofouling and corrosion technology.

Information on heat transfer in the low temperature range of 80 degrees to 40 degrees F is not available in the literature and must be established by a test program.

Research underway related to heat transfer on the working fluid side includes (1) evaluations of thermodynamic data, (2) comparative investigation of the mechanisms of nucleation and evaporation under thin film flow conditions, (3) comparative investigations of condensation for fluted or gregorig surfaces in two-phase flow with vapor shear. For water-side heat transfer, information is being obtained on comparative investigations of surface augmentations, boundary layer disrup-

tion and secondary flow generation. In addition, hydraulic studies are underway to determine internal fluid distribution, to quantify sea water corrosion, and to develop convenient design algorithms.

Biofouling on the seawater side of the evaporator represents a key technology issue. Permitting the growth of organisms or the deposition of inorganic material on the evaporator surfaces will interfere with their heat transfer properties and hence result in performance degradation. Biofouling may also occur on the sea water side of the condenser and on the hull. This will affect the hull buoyancy and drag (sea keeping ability). Maintenance requirements must be defined for compatibility with operational duty cycle requirements.

Research in these areas will utilize biofouling potential, rate and control information already assembled by the Navy, NOAA, and the Coast Guard.

The initial phase of the biofouling program is designed to determine biofouling and corrosion rates for ocean regions containing likely OTEC sites, and to evaluate candidate control methods for a range of heat exchanger materials (titanium, aluminum and plastic). The separate effects of fouling and corrosion will be quantified. Mechanical, chemical and other avoidance or control methods will be included.

The water intake areas of the OTEC structure are favorable for the growth of fouling organisms. These organisms must be kept out of the evaporator and condenser system. Intake screens will need to be cleaned of impinging nektonic and fouling organisms. Automatic cleaning systems may be needed to ensure that power plant operation is continuous.

Special instrumentation will be used at various locations to test biofouling potential and candidate control procedures. Biofouling measurements in the ocean were initiated at a site off Hawaii and will be extended to sites in the Caribbean, in the Gulf of Mexico, and in the Florida Current.

By the end of FY 1978, appreciable information will be available regarding biofouling rates as a function of local conditions, heat exchanger configuration, materials and internal flow conditions. In addition, biofouling avoidance and control methods will be defined to support the heat exchanger concept selection scheduled for late FY 1979.

Technology/Manufacturing Development

Heat exchanger costs comprise over 50 percent of OTEC power plant costs. Designs must be configured that can be produced at minimum cost. Modular designs, made of identical subassemblies, are most suitable for automatic or semiautomatic production. Subassemblies, configured so that multiple operations (tube forming, tube attachment) are performed simultaneously, are desirable. A producibility study is being performed to identify factors that reduce costs in the fabrication of tube and shell heat exchangers.

Other manufacturing development requirements will be identified from mission analysis studies. The industrial base needed to supply materials required to produce OTEC power plants and OTEC industrial complexes – in number and mixes sufficient to meet the 20 GWe market penetration goals – will be assessed. Current studies, for example, indicate that proliferation of power plants utilizing titanium heat exchangers may require an expansion of titanium production.

Analysis of OTEC development test requirements has established the need for early heat exchanger testing at large flow rates of cold and warm water that can best be satisfied by using the ocean thermal resource. The program plan identifies three ocean tests: 1 MWe, 5 MWe, and a 25 MWe power module. The 5 MWe pilot power plant platform will probably be different from that used for the 1 MWe heat exchanger test.

The 25 MWe power module test is planned to be conducted on a 100 MWe capacity demonstration hull configuration. Subsequently, one to four advanced generation heat exchanger configurations will then be tested on that platform. This will lead to a 100 MWe demonstration in FY 1984.

Facilities

A combination of (a) the current OTEC hardware technology status and subsequent need for development testing, (b) the requirement for scaled facilities for system test and demonstration and (c) the requirement (potential) for enlarged platform construction facilities has defined the need for OTEC (test) facilities (Reference 2). These facilities have been established as those required to provide the necessary "test bed" for OTEC components and then to demonstrate the feasibility of an OTEC plant to provide useful electrical power for connection to a utility grid or to supply power to an energy intensive process.

An analysis (Reference 2) of the OTEC development test requirements has established the need for early heat exchanger testing at large flow rates of cold and warm water that can be supplied by using the ocean thermal resource. The Program Plan identifies three ocean tests: One at 1 MWe, one at 5 MWe, and a 25 MWe module demonstration on a 100 MWe hull.

The 25 MWe module test will be conducted using a 100 MWe hull configuration. During subsequent tests, advanced generation (low cost) heat exchanger configurations will also be tested. This will be followed by a full 100 MWe demonstration in FY 1984/85.

Milestones relative to efforts in the Technology Base phase of the program include:

FY 1977, FY 1978
- Estimate influence of biofouling on heat exchanger performance and maintenance
- Estimate influence of corrosion on heat exchanger performance and life cycle
- Estimate projected performance and costs for various heat exchanger concepts

FY 1979
- Resolve uncertainties in working fluid evaporation and condensation efficiencies at low temperature differences

4 Program Decisions

There is an initial programmatic decision point (Figure 4 and Table 4) at the end of FY 77 based upon the performance of bench scale tests of four heat exchanger configurations: horizontal tube – thin film, horizontal tube – nucleate boiling, vertical tube – falling film, and trombone. If the performance is unsatisfactory, then the program can be cancelled or continued at a research and development level. During FY 78 is another major decision point. At this time, data on heat exchanger long term performance, heat exchanger size and performance, knowledge of advanced heat exchangers, hull configuration and applications will permit ERDA to fully evaluate the probable economic viability of OTEC. Secondly, platform configuration and heat exchanger selection for the Ocean Thermal demonstration system will be known. Lastly, in order to have a suitable platform available for the 1983 tests, it will be necessary to initiate design and development of the platform by FY 79. There is another major program review point after one year of testing of the early 1 MWe test article and 3 months of testing of a baseline 1 MWe test article. These tests will provide data on biofouling and corrosion in a large scale system, producing large heat exchangers, local heat transfer and erosion characteristics, and off-peak and transient performance behavior. It will be a major verification test of whether the 25 MWe module will be a viable system.

Another programmatic decision will be made in FY 77 on the need for a land-based test facility in the early 1980's. This decision will be heavily influenced by the nature of the government role in that time frame. The issue is whether a government facility that provides multiple heat exchanger tests capability is required for a successful commercialization scenario.

5 References

1. Ocean Thermal Energy Conversion (OTEC) Program Plan, pages III-25 to 28 in ERDA 49, June 1975

2. Proceedings, Third Workshop on Ocean Thermal Engery Conversion (OTEC), Gordon Dugger, ed., Applied Physics Laboratory, Johns Hopkins University, May, 1975

3. Program Approval Document – Solar Energy Development, Fiscal Year 1976 and Transition Quarter – ERDA Report dated March 30, 1975

4. Proceedings, Workshop on Legal, Political and Institutional Aspects of Ocean Thermal Energy Conversion, January 15-16, 1976, Mayflower Hotel, Washington, D.C.

5. Proceedings, Ocean Thermal Energy Conversion (OTEC) Workshop on Energy Utilization, June 17, 1976, Chicago, Illinois. Gilbert/Commonwealth Report, July 1976

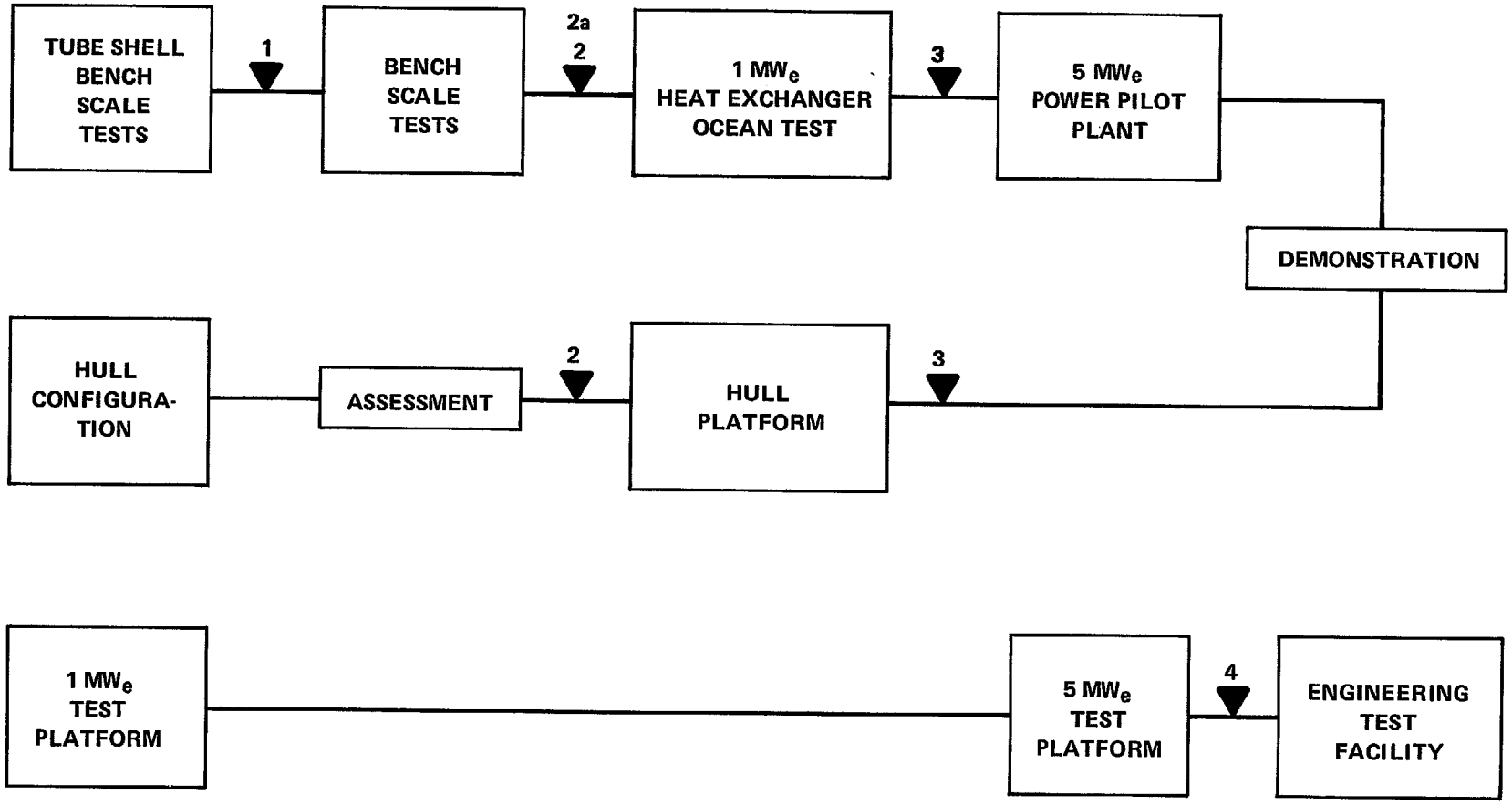


Figure 4—Decision Flow Diagram—Ocean Thermal Program

TABLE 4. KEY DECISIONS – OCEAN THERMAL ENERGY PROGRAM

Decision (Dates)	Information Required	Sources	Impact	Alternatives
1. Whether to proceed with development of heat exchanger test article hardware (FY 1978)	Heat exchange and heat transfer performance Performance goal for 25 MW_e module User interest Preliminary biofouling and cleaning data	Heat exchanger bench tests Research and development on surface enhancement Design of heat exchanger configurations Biofouling tests	Performance and cost of entire ocean thermal program (100s of millions of dollars)	NO GO Conduct further heat transfer R&D until performance is improved Proceed with 1 MW_e test article to gain ocean experience Provide incentives and let industry develop
2. Whether to proceed with developments of ocean thermal platform and heat exchanger to demonstration (FY 1979)	Advanced heat exchanger performance 25 MW_e module size, performance Hull configuration Heat exchanger long-term performance Applications sites User interest	Heat exchanger bench tests of advanced configurations Preliminary design of 25 MW_e module System studies Corrosion and biofouling data Mission studies, siting experiments	Performance and cost of entire ocean thermal program (100s of millions of dollars)	Conduct further heat transfer R&D until performance is improved Provide incentives and let industry develop
2a. Whether to proceed with open cycle or alternative working fluids (FY 1978)	Performance and cost estimates for alternatives Applications	R&D tests Cycle Plant evaluation Mission studies	Second ocean thermal system development	Develop only NH_3 closed cycle system Redirect program to alternate
3. Whether to proceed with 25 MW_e module detailed design and construction (FY 1980)	Early 1 MW_e test article data in ocean environment Baseline 1 MW_e test article data in ocean environment Long-term performance Effect on biota and thermal gradient Cost of large heat exchanger	1 MW_e tests Biofouling and corrosion experiments Analyses and experiments	Possible poor long-term heat exchanger performance	Delay of program until satisfactory solution is found
4. Whether to proceed with land-based Engineering Test Facility (FY 1977)	Test requirements in later portion of program Philosophy of Government role in the 1980s Cost and flexibility of land-based facility	Test requirement analysis Facility study	Need for a land facility (~$50 million)	GO/NO GO on land facility

OTEC FUNDING FOR FISCAL YEARS 1972 THROUGH 1976*

(Budgetary obligations in thousands of dollars: ERDA and NSF combined)

Program Activity	Fiscal Year				
	1972	1973	1974	1975	1976*
Program Support				111	2,062
Definition and Systems Planning					
— Systems studies and workshops	85	230	530	786	237
— Test program requirements					1,091
— Mission analysis					360
— Energy utilization				360	202
— Marine environment				36	312
— Environmental impacts				205	457
— Thermal resource assessment and siting studies			50	172	
— Legal and institutional studies				61	145
Engineering Development					
— Heat exchangers					250
Advanced Research and Technology					
— Heat exchangers			150	435	1,669
— Exploratory power cycles				27	
— Submarine electrical cables				50	
— Biofouling and corrosion				207	1,303
— Ocean engineering				505	497
TOTALS	85	230	730	2,955	8,585*

*Includes funding for Transition Period (July 1, 1976 to Sept. 30, 1976).

PROJECT SUMMARIES

Introduction

The following pages summarize both OTEC projects that are presently under contract and projects that have already been completed but are still of current interest. The projects listed are or were supported by various U.S. Government agencies interest in OTEC. Those agencies include the U.S. Energy Research and Development Administration (ERDA), the National Science Foundation (NSF), the Maritime Administration (MARAD) of the U.S. Department of Commerce, the Office of Sea Grant of the National Oceanic and Atmospheric Administration (NOAA), the Federal Energy Administration (FEA), and the U.S. Department of the Navy.

PROGRAM SUPPORT

CONTRACTOR & ADDRESS	CONTRACT NO.
Gilbert Associates, Inc. 1828 L Street, N.W., Suite 1201 Washington, D.C. 20036 SUBCONTRACTOR: Frederic R. Harris, Inc.	ERDA E(11-1)-2847
	PERIOD OF PERFORMANCE January 1, 1976 to December 31, 1976
PRINCIPAL INVESTIGATOR John van Summern (202) 331-0252	**FUNDING** $1,062,014* (to September 30, 1976)

TITLE

Architect-Engineering services in support of the OTEC program

SUMMARY

This project is to provide architect-engineering support services for a variety of OTEC technical, programmatic and design efforts. The work required to support the program includes the following activities: 1) technical monitoring and review of research projects, proposals, and system studies, 2) system integration tradeoff analysis, 3) recommendations for test programs, and 4) dissemination of information with regard to the program.

To accomplish this work, the project is divided into five key tasks. These tasks relate directly to the above mentioned activities, and cover an initial period of one year. Procedures that help coordinate program activities and ensure optimum utilization of OTEC program resources are being emphasized during the initial effort. The contractor is also responsible for technical recommendation of ocean platform concepts for the initial test facilities and overseeing the technical analysis of these facilities.

*Not including a total of $212,000 subcontracted to Mechanics Research, Inc. and to Rosenblatt & Son, Inc. (cf. pp. 30 and 31)

PUBLICATIONS AVAILABLE

PROGRAM SUPPORT

CONTRACTOR & ADDRESS	CONTRACT NO.
Battelle Pacific Northwest Laboratories (PNL) Battelle Boulevard, P.O. Box 999 Richland, Washington 99352	ERDA AT (45-1)-1830
	PERIOD OF PERFORMANCE Dec. 10, 1975 to Sept. 30, 1976
PRINCIPAL INVESTIGATOR Lyle D. Perrigo (509) 946-2113	FUNDING $169,000*

TITLE

Ocean thermal energy conversion biofouling and corrosion study

SUMMARY

This project in biofouling and corrosion development is providing 1) the necessary work to define, prevent, and alleviate biofouling and corrosion problems associated with OTEC systems, and 2) the proper management of various projects that should be undertaken in this area to achieve program objectives. Biofouling and corrosion of the heat transfer surfaces in OTEC systems are believed to be controlling factors in the potential success of the OTEC concept. Effort is being focused in this critical area.

*This amount is for contract administration; an additional $1,303,000 has been provided to date for projects being subcontracted by PNL. Projects subcontracted to date and/or projects being managed by PNL are included in the Advanced Research and Technology section.

PUBLICATIONS AVAILABLE

PROGRAM SUPPORT

CONTRACTOR & ADDRESS	CONTRACT NO.
U. S. Naval Facilities Engineering Command 200 Stovall Street Alexandria, Virginia 22332	ERDA E(49-26)-1000
	PERIOD OF PERFORMANCE Feb. 24, 1975 to Sept. 30, 1976
PRINCIPAL INVESTIGATOR Lawrence K. Donovan (202) 325-0505	FUNDING $288,000

TITLE

Technical management of the OTEC ocean engineering program activity

SUMMARY

The object of this project is to perform the following services for ERDA: 1) program management assistance and consultation for assistance in the OTEC program planning, preparation and evaluation of program solicitations, participation in overall program evaluation, and coordination with other agencies providing support to the ERDA in other technology aspects of OTEC development, 2) management and technical coordination of all Navy facility access required for utilization of Navy test and fabrication facilities in support of OTEC Program, 3) technical evaluation of system, component, and technology development proposals, monitoring and evaluation of ERDA contractor work specifically assigned to NAVFAC for technical direction, transfer of Navy technology to ERDA contractors, and participation in program technical reviews and workshops, 4) technical direction, monitoring, and evaluation of specific research and development projects by ERDA or Navy contractors as assigned, and 5) coordination, monitoring, and evaluation of ERDA-funded research and development projects to be accomplished in-house by Navy organization and laboratories.

PUBLICATIONS AVAILABLE

PROGRAM SUPPORT

CONTRACTOR & ADDRESS	CONTRACT NO.
Oak Ridge National Laboratory (ORNL) Post Office Box Y Oak Ridge, Tennessee 37830	ERDA W-7405-eng-26
	PERIOD OF PERFORMANCE Dec. 11, 1975 to Sept. 30, 1976
PRINCIPAL INVESTIGATOR John Michel (615) 483-8611, Ext. 35000	**FUNDING** $107,000

TITLE

Program development for OTEC heat exchangers

SUMMARY

This project provides technical planning input for the OTEC heat exchanger program activity, describing in some detail the organization, manning, and proposed methodology. Currently, ORNL is monitoring ongoing R&D contracts in various aspects of OTEC heat exchangers and provides consulting services to the various phases of the program. ORNL efforts are specifically directed towards consulting in advanced heat exchanger concepts, reviewing the current state-of-the-art, conducting a literature search, and developing optimization techniques needed for system evaluation.

PUBLICATIONS AVAILABLE

PROGRAM SUPPORT

CONTRACTOR & ADDRESS	CONTRACT NO.
Tefft, Kelly and Motley, Inc. 1225 Connecticut Avenue, N.W. Washington, D.C. 20030	ERDA E(49-18)-2311
	PERIOD OF PERFORMANCE April 29, 1976 to September 30, 1976
PRINCIPAL INVESTIGATOR R. Clark Tefft (202) 659-2650	FUNDING $53,000

TITLE

OTEC program support

SUMMARY

This project provides analysis and program support in accordance with specific task assignments.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Massachusetts, Univ. of, Civil Engineering Dept. Amherst, Mass. 01002 SUBCONTRACTORS: United Aircraft Research Labs; Sea Solar Power, Inc.; and Naval Underwater Systems Center	NSF GI-34979 and AER-7510670
	PERIOD OF PERFORMANCE July, 1972 to December, 1975
PRINCIPAL INVESTIGATOR William E. Heronemus (413) 545-0215	**FUNDING** $425,000

TITLE
Technical and economic feasibility of the ocean thermal differences process as a solar-driven energy process with potential for significant impact on the United States energy market

SUMMARY

This was an investigation into the technical and economic feasibility of generating significant amounts of energy for the U.S. market using an ocean thermal differences process. An initial concept was that such a system would be ocean-sited in the Gulf Stream. The work emphasized an analysis of power cycles, the cold water pumping problem, heat exchanger theory and design, hull design, siting, anchoring, and the energy umbilical to the market ashore. This led to the conceptualization of one total system. Several plans of action for the experimental phase and the production planning phase were prepared.

The ultimate power potential of a 15 mile wide by 550 mile long area of the Gulf Stream resource (extending from Charleston, S.C. to the Florida Keys) was estimated to be of the order of 2 trillion kWh per year, and this power could be transmitted to shore by submarine cable. Critical subsystems and components were identified, and the technical basis for their design and selection was discussed.

Plate-fin heat exchangers made of 90/10 Cu-Ni, with propane flowing up (for evaporators) or down (for condensers) through small passages in the plates, and seawater flowing horizontally between the plates, were selected for the power system analyzed. The platform design for that system concept was a submerged catamaran structure, with the evaporators staggered serially in height in six tiers spaced longitudinally above twin concrete hulls containing the condensers, pumps and turbine generators. The associated cold-water inlet pipe was 1500 feet in length, 87 feet in diameter, and hinged between the hulls using a joint of the gun-buckler variety. A potential assembly/deployment plan for this power plant was developed.

PUBLICATIONS AVAILABLE
See Bibliography Reference No. 19

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Carnegie-Mellon University Schenley Park Pittsburgh, PA 15213	NSF GI-39114
	PERIOD OF PERFORMANCE June 01, 1973 to September 30, 1975
PRINCIPAL INVESTIGATOR Clarence Zener (412) 621-2600, Ext. 229	**FUNDING** $360,500

TITLE
Solar ocean-based power plants

SUMMARY
This study was an attempt to develop analytical cost and performance models for OTEC components and subsystems, integrate the models to form a complete OTEC power cycle, employ computer optimization for minimum cost design, examine environmental factors limiting plant size at typical sites, and conduct a preliminary assessment of OTEC technology.

In a later phase, various energy utilization schemes were costed and the transient behavior of OTEC exchangers modeled analytically.

The major findings of the study were:

1) Double-fluted surfaces shell-and-tube exchangers may reduce costs substantially.

2) Ammonia and aluminum are compatible materials for low cost heat exchangers.

3) Manifolding is required to reduce pressure drops on the ammonia side within the exchangers.

4) Analytical models for all OTEC components were derived as a means to estimate and optimize system performance through geometric programming.

5) OTEC plants, 200-400 MWe, can be sited 15 miles apart if ocean current is less than 0.1 ft./sec.

6) The Gulf of Mexico is a potential site for OTEC to produce electricity and chemicals for delivery to U.S. shores.

7) Electricity is the most economic product, followed by hydrogen. Ammonia production is not competitive at 1975 prices and cost estimates.

8) There are no known major environmental hazards resulting from OTEC deployment.

PUBLICATIONS AVAILABLE
See Bibliography Reference No. 20

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS
Carnegie-Mellon University
College of Engineering
Schenley Park
Pittsburgh, PA 15213

CONTRACT NO.
ERDA E(11-1)-2895

PERIOD OF PERFORMANCE
Jan. 1, 1976 to Sept. 30, 1976

PRINCIPAL INVESTIGATOR
Abrahim Lavi
(412) 621-2600, Ext. 8712

FUNDING
$106,831

TITLE
Systems analysis and engineering studies for ocean thermal energy conversion

SUMMARY
This study is to resolve key questions of system design, modeling and control, critical to the economic implementation of OTEC, emphasizing concept feasibility and capital cost requirements.

Three tasks are underway:

1) Development of analytical models for the study of transient behavior and control and instrumentation techniques of ocean thermal power plants.

2) The design of minimum cost shell and tube heat exchangers employing falling film. The design must meet specified water and vapor pressure loss and given heat flux throughout. The technique of geometric programming is being employed.

3) The design of minimum cost self-sufficient OTEC power plant. The objective is to determine the smallest OTEC plant at the lowest cost which can be operated year-round without auxiliary power.

Results to date are:

1) The dynamic modeling indicates a strong need for experimental data. Theoretical information is inadequate.

2) Fluted vertical tube heat exchangers can reduce the cost of materials by as much as 50%.

3) A 10 kWe output plant with a cold-water pipe not exceeding 1,000 ft. is feasible without added cost.

4) Pressure drop on the ammonia side can be reduced by more than 50% if the tubes are arranged to form tributaries and mains to distribute the vapor.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Lockheed Missiles and Space Co., Inc. P.O. Box 504 Sunnyvale, California 94088 SUBCONTRACTORS: Bechtel Corp., T.Y. Lin International	NSF C-937 PERIOD OF PERFORMANCE June 21, 1974 to March 20, 1975
PRINCIPAL INVESTIGATOR Lloyd C. Trimble (408) 742-5035	FUNDING $328,188

TITLE
Research on an engineering evaluation and test program

SUMMARY

The research team performed a system analysis and engineering evaluation of available concepts for ocean thermal energy conversion, including concepts described by Karig in ASME paper 72-WA/Oct. 12. The approach included evaluating prior analyses, establishing a baseline system design, determining component parametric costs, and optimizing an integrated ocean platform-mounted power plant. Test program requirements were studied and formulated, leading to the preparation of a test plan based upon components to be tested, test data requirements, and a test facilities plan.

PUBLICATIONS AVAILABLE
See Bibliography Reference No. 22

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
TRW, Inc. Systems and Energy Group 1 Space Park Redondo Beach, Calif. 90278 SUBCONTRACTORS: Global Marine Development, Inc. United Engineers & Constructors	ERDA E(04-3)-1089 NSF C-958
	PERIOD OF PERFORMANCE July 30, 1974 to April 30, 1975
PRINCIPAL INVESTIGATOR Robert H. Douglass (213) 535-2446	**FUNDING** $391,427

TITLE

OTEC: Research on an engineering evaluation and test program

SUMMARY

The research team performed a system study to evaluate concepts for ocean thermal energy conversion and to formulate a test program, including the conceptual design of test facilities. The initial state-of-the-art review evaluated existing analytical tools as well as concepts. A baseline concept was selected and costed. Test configurations for evaluation of systems, subsystems, components, and/or material levels were selected, and a test program plan created.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 23

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
National Academy of Sciences 2101 Constitution Avenue Washington, D.C. 20418	ERDA E(49-18)-2347
	PERIOD OF PERFORMANCE June 01, 1976 to March, 1977
PRINCIPAL INVESTIGATOR Marine Board, National Academy of Engineering Denzil Pauli (202) 389-6602	**FUNDING** $30,000

TITLE

Review of OTEC systems

SUMMARY

The purpose of this project is to provide a review of the technical and economic feasibility of OTEC systems. This effort includes an engineering assessment and analysis of, as well as guidance for, implementation and integration of existing systems studies and possible new areas requiring engineering research.

To date, two review committee meetings have been held. The first meeting was held in Washington, D.C. in June 1976. The second review was held in Los Angeles in August, 1976.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Applied Physics Laboratory, Johns Hopkins University VIA: Naval Sea Systems Command (NAVSEA) Dept. of the Navy, Code: SEA 0253W Arlington, Virginia 20360	ERDA E(49-26)-1001
	PERIOD OF PERFORMANCE February 27, 1975 to Sept. 26, 1975
PRINCIPAL INVESTIGATOR Gordon L. Dugger (301) 953-7100, Ext. 7462	**FUNDING** $25,000

TITLE
Ocean Thermal Energy Conversion Workshop (Houston, May 08-10, 1975)

SUMMARY

This project was for the organization, coordination, and documentation of the Third Workshop on Ocean Thermal Energy Conversion (OTEC) held in Houston, Texas, May 08-10, 1975, following the 1975 Offshore Technology Conference. The status of OTEC programs was reviewed, and special emphasis given to Working Group discussions and reports on critical issues.

A Workshop Proceedings volume was prepared and distributed following the Workshop. It contains (a) papers presented at the Workshop, (b) transcript of discussions; and (c) reports from the six assigned Working Groups.

PUBLICATIONS AVAILABLE
See Bibliography Reference No. 25

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS

Colorado School of Mines
Golden, Colorado 80401

SUBCONTRACTOR: Westinghouse Electric Corp.

CONTRACT NO.

ERDA E(29-2)-3723

PERIOD OF PERFORMANCE

June 01, 1976 to May 30, 1977

PRINCIPAL INVESTIGATORS

Frank Mathews
(303) 279-0300, Ext. 844

A. D. Watt
(303) 856-3465

FUNDING

$99,849

TITLE

An evaluation of open-cycle thermocline power systems

SUMMARY

This project is a feasibility and costing study of an open cycle system that may be competitive with the closed cycle system. In this project the feasibility of using an open cycle system for the production of electric power from ocean thermocline is determined. This is accomplished by: 1) developing performance and cost relations in parametric form for the thermocline, 2) developing performance/costing program arriving at minimum cost per rated kWe output for system component combinations in the 1 to 100 megawatt range, 3) developing preliminary engineering designs for the most cost-effective of open cycle systems considered, and 4) estimating installed capital and operating costs for the most cost-effective system and determine cost estimates for electric energy.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Systems Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Sea Solar Power, Inc. 1615 Hillock Lane York, Pa. 17403	NSF GI-44213
	PERIOD OF PERFORMANCE June 24, 1974 to March 23, 1975
PRINCIPAL INVESTIGATOR J. Hilbert Anderson (717) 741-0884	**FUNDING** $31,100

TITLE

Design, construct, and test an operating model of a sea solar power plant

SUMMARY

This project was for the design, construction and testing of a portable operating model of an ocean thermal energy conversion plant. The operation of the plant shows that power can be generated with simulated warm ocean surface water together with simulated cold water from depth. The model utilizes a tank of warm water at room temperature (72°F) and a tank of cold water (32°F), heat exchangers, a small turbine, and a belt-driven generator. A rotating light, powered by electricity generated by the model, provides visualization of the system performance. The work included the design, construction and testing of the model. The costs of design and construction were shared by the principal investigator. Testing was undertaken utilizing several working fluids and varying operating conditions; these included using R-11 refrigerant and varying the output power with input temperature difference. Turbine output was measured, and turbine efficiency calculated.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 27

DEFINITION AND SYSTEM PLANNING
Test Program Requirements

CONTRACTOR & ADDRESS	CONTRACT NO.
Lockheed Missiles and Space Co., Inc. P.O. Box 504 Sunnyvale, California 94088 SUBCONTRACTORS: Bechtel Corp. and Stanford Research Institute	ERDA E(04-3)-1156 **PERIOD OF PERFORMANCE** December 10, 1975 to August 26, 1976
PRINCIPAL INVESTIGATOR Lloyd C. Trimble (408) 742-5035	**FUNDING** $550,000

TITLE
Test facilities requirements definition

SUMMARY
This study was to develop alternative, non site-specific OTEC facilities and ocean platform requirements for an integrated OTEC test program that may include land and ocean test facilities. Alternative OTEC systems and equipment which must be developed and tested were defined and analyzed. The study included development of cost, schedule, and performance data for each of the alternative OTEC test facility requirements, and the performance of tradeoff analyses relative to these factors. The study results are to be documented in sufficient detail to enable ERDA to identify and examine all data considered, and to perform an independent evaluation of and selection between the alternatives.

Specific land sites and ocean test platforms were not to be considered in this study. The key objective of the study was to provide and consider a spectrum of possible OTEC test facility requirements, both ocean-based and land-based, and to perform cost-benefit-timing tradeoff analyses for those options.

Specific tasks under this contract were:

1) Establishment of system testing requirements, by reviewing, updating and utilizing existing conceptual baseline design studies as the primary information source, to conceptualize and analyze alternative system test configurations. From those configurations, to prepare testing plans.

2) Establishment of component testing requirements, proceeding similarly as in 1).

3) Definition of conceptualized testing requirements for Advanced Research and Technology.

4) Definition of conceptualized testing requirements for Energy Utilization technology.

5) Establishment of test facilities support requirements and associated costs.

6) Performance of a systems analysis of overall test facilities requirements, including space and resource requirements, scheduling and cost.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Test Program Requirements

CONTRACTOR & ADDRESS	CONTRACT NO.
TRW, Inc. Systems and Energy Group 1 Space Park Redondo Beach, California 90278 SUBCONTRACTOR: Global Marine Development, Inc.	ERDA E(04-3)-1158
	PERIOD OF PERFORMANCE Dec. 10, 1975 to August 26, 1976
PRINCIPAL INVESTIGATOR Robert H. Douglass (213) 535-2446	FUNDING $529,000

TITLE

Test facilities requirements definition

SUMMARY

This study was to develop alternative, non site-specific OTEC facilities and ocean platform requirements for an integrated OTEC test program that may include land and ocean test facilities. Alternative OTEC systems and equipment which must be developed and tested were defined and analyzed. The study included development of cost, schedule, and performance data for each of the alternative OTEC test facility requirements, and the performance of tradeoff analyses relative to these factors. The study results are to be documented in sufficient detail to enable ERDA to identify and examine all data considered, and to perform an independent evaluation of and selection between the alternatives.

Specific land sites and ocean test platforms were not to be considered in this study. The key objective of the study was to provide and consider a spectrum of possible OTEC test facility requirements, both ocean-based and land-based, and to perform cost-benefit-timing tradeoff analyses for those options.

Specific tasks under this contract were:

1) Establishment of system testing requirements, by reviewing, updating and utilizing existing conceptual baseline design studies as the primary information source, to conceptualize and analyze alternative system test configurations. From those configurations, to prepare testing plans.

2) Establishment of component testing requirements, proceeding similarly as in 1).

3) Definition of conceptualized testing requirements for Advanced Research and Technology.

4) Definition of conceptualized testing requirements for Energy Utilization technology.

5) Establishment of test facilities support requirements and associated costs.

6) Performance of a systems analysis of overall test facilities requirements, including space and resource requirements, scheduling and cost.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING

Test Program Requirements

CONTRACTOR & ADDRESS	
Mechanics Research, Incorporated 9841 Airport Blvd. Los Angeles, California 90045	Subcontract to Gilbert Associates Contract ERDA e(11-1)-2847
	PERIOD OF PERFORMANCE June 09, 1976 to November 15, 1976
PRINCIPAL INVESTIGATOR Robert Falconer (213) 670-4650	FUNDING $105,000

TITLE

Feasibility study: Hughes Mining Barge (HMB-1) for an Early Ocean Test Platform (EOTP)

SUMMARY

The technical and economic feasibility of converting the Hughes Mining Barge (HMB-1) to a test platform for 1 MWe (40 MWt) cycle components is being examined.

The systems requirements are being analyzed and specifications are being drawn up to spell out the system and support requirements along with optimization of the systems and equipment.

Conceptual designs are being prepared for situating the test articles, support facilities and mooring arrangements. Lists of equipment for deployment, operations and support are also being prepared.

An overall plan for construction, acquisition of support elements and deployment is also being developed, and cost estimates and time schedules are being developed.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Test Program Requirements

CONTRACTOR & ADDRESS	
Rosenblatt, M., & Son, Inc. 350 Broadway New York, New York 10013	Subcontract to Gilbert Associates Contract ERDA E(11-1)-2847
	PERIOD OF PERFORMANCE August 13, 1976 to December 5, 1976
PRINCIPAL INVESTIGATOR Naresh M. Maniar (212) 431-6900	FUNDING $107,000

TITLE

Vessel utilization assessment

SUMMARY

An assessment of potential candidate vessels for use as an Early Ocean Test Platform (1 MWe/40 MWt) is being performed.

One objective of this study is to determine the most satisfactory vessel(s) that can serve as an Early Ocean Test Platform (EOTP) for testing OTEC hardware components at sea. A second objective is to identify the general classes of vessels which may serve as host for a 5 MWe EOTP OTEC system and for 25 MWe system tests.

The EOTP study involves development and costing of conceptual designs and layouts, and the identification of support facilities, mooring arrangements and of all equipment required for deployment, operation, and support.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Mission Analysis

CONTRACTOR & ADDRESS

Aerospace Corporation
P.O. Box 92957
Los Angeles, California 90009

CONTRACT NO.

ERDA E(04-3)-1101

PERIOD OF PERFORMANCE

May 01, 1976 to October 31, 1976

PRINCIPAL INVESTIGATOR

George C. McKoy
(213) 648-6406

FUNDING

$210,000

TITLE

Mission analysis for OTEC systems

SUMMARY

This study addresses the many interrelated factors (especially economics) which bear on the overall attractiveness of various ocean thermal energy conversion (OTEC) concepts. It provides a technical and economical rationale for the on-going OTEC program and identifies and compares viable program alternatives. The study consists of three basic tasks: 1) area definition and siting analyses that identify and describe the areas potentially available and suitable for OTEC system siting, and to rank these in terms of various siting criteria that are being developed, 2) identification and prioritization of a number of OTEC-related energy utilization concepts, including technical and economic analyses and risk assessments and comparison of this analysis with utilization of other energy alternatives, and 3) marketability and market penetration potential to evaluate marketability of products for preferred OTEC systems at various locations. Critical external issues will be identified and various OTEC market penetration scenarios and strategies will be examined. Energy savings and other impacts will be estimated for various scenarios and degrees of market penetration.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Mission Analysis

CONTRACTOR & ADDRESS	CONTRACT NO.
General Electric Company/TEMPO 777 Fourteenth Street, N.W. Washington, D.C. 20005	ERDA E(49-18)-2421
	PERIOD OF PERFORMANCE May 15, 1976 to Dec. 14, 1976
PRINCIPAL INVESTIGATOR Edward J. Tschupp (202) 637-4000	FUNDING $150,000

TITLE
Mission analysis study

SUMMARY
This study provides a mission analysis of OTEC which supports governmental, institutional, and industrial decision-making with respect to the utilization of the ocean's thermal energy resources on a regional scale. An assessment of the potential for large-scale utilization of ocean thermal energy for various applications is being provided. The major tasks are:

- Identification of high priority missions
- Development of implementation scenarios for high priority mission applications
- Development of an OTEC system deployment plan
- Legal, institutional, and political analysis
- Definition of the consequence of implementation and deployment of an OTEC system.

PUBLICATIONS AVAILABLE

34

DEFINITION AND SYSTEM PLANNING
Mission Analysis

CONTRACTOR & ADDRESS	CONTRACT NO.
Lockheed Missiles & Space Co., Incorporated P.O. Box 504 Sunnyvale, California 94088	FEA P-05-76-1933-0
	PERIOD OF PERFORMANCE August to October, 1975
PRINCIPAL INVESTIGATOR Lloyd C. Trimble (408) 742-5035	**FUNDING** $2,495

TITLE
Potential of accelerating commercialization of ocean thermal energy conversion

SUMMARY

This study was to compile and supply existing and available information pertinent to the potential accelerated production of OTEC power plants, and regarding the associated costs. The work was to include an analysis of the potential demand for OTEC electricity and OTEC energy-intensive products.

Results included an analysis of accelerated OTEC power-plant production using four supply scenarios (20 GWe by 1990, 20 GWe by 1995, 20 GWe by 2000, and business-as-usual). Corresponding costs were derived, based upon a set of supply assumptions. Potential competitive markets and applications of 20 GWe of OTEC energy were identified, and a preliminary discussion of commercialization constraints and incentives was prepared.

PUBLICATIONS AVAILABLE
See Bibliography Reference No. 34

DEFINITION AND SYSTEM PLANNING
Mission Analysis

CONTRACTOR & ADDRESS	CONTRACT NO.
Applied Physics Laboratory Johns Hopkins University Laurel, MD 20810 SUBCONTRACTORS: Woods Hole Oceanographic Institute and Hydronautics, Inc.	MARAD 5-38054
	PERIOD OF PERFORMANCE April 1, 1975 to November 30, 1976
PRINCIPAL INVESTIGATOR Gordon L. Dugger (301) 953-7100, Ext. 7462	**FUNDING** $235,000*

TITLE

An analysis of the maritime and construction aspects of OTEC plant-ships

SUMMARY

The technical feasibility of a sea-going OTEC plant-ship based in tropical ocean waters and producing one of several energy-intensive products was examined. The analysis showed that such plant-ships can be built, i.e., are "technically feasible," and that they could be in operation circa 1986. Evidence was provided suggesting that OTEC plant ships can produce ammonia and other energy-intensive products such as aluminum at competitive costs.

OTEC plant-ships were considered for the production of liquid hydrogen, and their components are discussed and costed. Sites are suggested and analyzed for sea conditions, temperature gradients, weather conditions, bottom conditions, and location. Materials are studied and evaluated with respect to corrosion, biofouling, and general performance.

Locations of energy-intensive product production and distribution systems for continental USA are indicated. The impact on the U.S. merchant marine is ascertained. The legal aspects of operating an OTEC plant-ship are discussed.

*Additional information and funding were contributed by the following institutions that were not under subcontract. The amounts, not included in FUNDING above, are: Sun Shipbuilding, Chester, PA, $125,000 effort; Avondale Shipyards, New Orleans, LA, $50,000 effort; Leboeuf, Lamb, Leiby, and MacRae, a study on the law; and Commercial Finance Co., expertise on financing ships.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 35

DEFINITION AND SYSTEM PLANNING
Energy Utilization

CONTRACTOR & ADDRESS	CONTRACT NO.
Institute of Gas Technology Energy System Research 3424 S. State Street ITT Center Chicago, Illinois 60616	NSF C-1008
	PERIOD OF PERFORMANCE May 01, 1975 to April 30, 1976
PRINCIPAL INVESTIGATOR Derek P. Gregory (312) 567-3893	FUNDING $125,000

TITLE

An optimization study of ocean thermal energy delivery systems based on chemical energy carriers

SUMMARY

This study provided an engineering and economic analysis of chemical energy-carrier alternatives for transportation of energy from large-scale floating OTEC power plants to wholesale energy markets. The chemical energy carriers analyzed in this study are hydrogen (both as a gas and as a liquid) and ammonia, since both are marketable fuels for industrial, commercial, and residential applications. The project focused on 1) chemical energy production, 2) assessment of present chemical energy transmission technologies for hydrogen and ammonia, 3) projection of technological advancements in delivery system elements, including cost goals for improving energy utilization efficiency, investment costs, and unit operations costs for the various elements, 4) synthesis of 2 and 3 above, 5) evaluation of land-based terminal facilities, 6) reconversion of chemical energy to electricity and onshore fertilizer production, 7) determination of the sensitivity of the systems to variations in operating parameters, and 8) recommendations regarding future R&D.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 36

DEFINITION AND SYSTEM PLANNING
Energy Utilization

CONTRACTOR & ADDRESS

Institute of Gas Technology
3424 State Street
Chicago, Illinois 60616

CONTRACT NO.

ERDA E(49-18)-2426

PERIOD OF PERFORMANCE

June 24, 1976 to June 23, 1977

PRINCIPAL INVESTIGATOR
Nicholas Biederman
(312) 567-3930

FUNDING

$175,355

TITLE

Alternative energy transmission systems from OTEC plants

SUMMARY

The study will concurrently evaluate the feasibility of and generate conceptual designs for two concepts for transporting ocean thermal energy to shore. One concept deals with an onboard electrical system to produce high temperature heat, and the use of a thermal storage medium to store and ship this energy and subsequently use this thermal energy for electric generation at the shore facility. The other concept would take hydrogen produced by water electrolysis and react it with carbon dioxide aboard the OTEC platform to produce carbonaceous fuels. Two alternatives exist as the source of this carbon dioxide: a back-haul scheme that would bring carbon dioxide from an onshore source to the OTEC platform, and the use of carbon dioxide which is dissolved in the cold seawater used by the OTEC plant.

This study will be conducted to allow a uniform comparison of these alternatives with the results of the previous OTEC analysis conducted by IGT.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Energy Utilization

CONTRACTOR & ADDRESS

DSS Engineers, Inc.
7483 Northwest 4th Street
Fort Lauderdale, Florida 33317

CONTRACT NO.

ERDA E(40-1)-4915

PERIOD OF PERFORMANCE

April 22, 1975 to April 21, 1976

PRINCIPAL INVESTIGATOR

Baldur Lindal
(305) 792-6660

FUNDING

$136,000

TITLE

Preliminary research on an Ocean Energy Industrial Complex (OEIC)

SUMMARY

The objective of this research was to investigate the technical and economic feasibility of developing an industrial complex producing prime products in conjunction with a floating ocean thermal energy power plant. It is desirable to make maximum use of the ocean resources (energy and raw materials) at the site. Previous studies concerning the extraction of chemicals and minerals from seawater have shown that this is both logical and economic if the scale of operation, geographical location, transportation, and markets are favorable. It appears that these conditions are favorable for an Ocean Energy Industrial Complex (OEIC).

A preliminary market analysis covering 30 possible energy-intensive products classified 12 as high demand, high growth rate. Costs of shipping bulk solids and liquids to and from the ocean site will amount to 1-5% of the product sales price. Three possible sites are selected for OEIC's, with an area in the Caribbean about 200 miles north of Caracas considered best. Based on projected demands for products and economical plant sizes, production quantities are selected for two base-line complexes: a sea chemicals complex requiring 300 MWe and an organic chemicals complex requiring 400 MWe. A total of 25 individual plants or processes are analyzed. The main process selected for concentration and crystallization in the sea chemicals and plastic complex is the electric arc process. Ammonia can be produced from by-product hydrogen. The surface vessel concept proposed by TRW-Global Marine was adopted for the base-line complexes. A single vessel was selected to house the OTEC, process equipment and storage facilities. Layouts for a sea chemicals complex on such a vessel are presented. From an analysis of environmental considerations, it was concluded that OEIC's could be constructed and operated with no adverse environmental impact. Detailed capital and operating cost information has been developed and presented. It was concluded that producing energy-intensive products at integrated OEIC's is technically sound and economically viable.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 38

DEFINITION AND SYSTEM PLANNING
Energy Utilization/Open-Ocean Mariculture

CONTRACTOR & ADDRESS

Columbia University
Lamont-Doherty Geological Observatory
Palisades, New York 10964

CONTRACT NO.

ERDA AT(11-1)-2581

PERIOD OF PERFORMANCE

April 4, 1975 to July 1, 1976

PRINCIPAL INVESTIGATOR

Oswald A. Roels*

FUNDING

$126,000

TITLE

Marine Pastures: A by-product of large (100 Megawatts or larger) floating ocean thermal power plants

SUMMARY

The economic feasibility of large, floating ocean thermal power plants will depend upon both the costs of power production and the value of possible by-products. The question of technical and economic feasibility of one adjunct process, that of open-ocean mariculture, was approached through this study of how to utilize the nutrient-rich cold-water effluents of OTEC power plants for that application.

This project examined this possibility through four approaches:

1) Physical/Chemical—The fate of deep water discharged at the surface was determined experimentally, including its mixing rate with surface water and the vertical and horizontal migration of the resulting mixture of surface water and deepsea water.

2) Primary Production—The indigenous phytoplankton species best suited for this open-ocean mariculture were determined, based upon measurements of comparative growth rates in differing mixtures of deep and surface water, efficiency of nutrient utilization and nutritional value for the second trophic level.

3) Secondary Producers—Various species of shellfish (oysters, clams, and scallops) were grown in raft and case cultures suspended in the open sea. Simultaneous small-scale growth tests were conducted in shallow water near shore, using the same species of phytoplankton and shellfish. That water was enriched with a continuous flow of water from a depth of 870 meters.

4) Scale-Up—An engineering and economic feasibility study was conducted, based upon the results of 1), 2), and 3), to determine the possibility of producing commercially valuable filter-feeding (shell) fish.

*Dr. Roels is now the Director of the Port Aransas Marine Laboratory, Marine Science Institute, University of Texas, Port Aransas, Texas 78373. Tel: (512) 749-6757

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING

Marine Environment

The projects on Marine environment summarized on the following three pages are under the management of the Naval Facilities Engineering Command (NAVFAC) of the U.S. Department of the Navy.

DEFINITION AND SYSTEM PLANNING
Marine Environment

CONTRACTOR & ADDRESS	CONTRACT NO.
Hawaii, University of Dept. of Ocean Engineering 2565 The Mall Honolulu, Hawaii 96822	ERDA E(04-3)-0235
	PERIOD OF PERFORMANCE April 21, 1975 to Sept. 1, 1976
PRINCIPAL INVESTIGATOR Charles L. Bretschneider (808) 948-8110	FUNDING $36,000

TITLE

Operational sea state and design wave criteria for OTEC projects

SUMMARY

The purpose of this project was to define the ocean environmental factors which determine the environment in which floating ocean thermal power plants operate, so as to enable the estimation of the environmental loads those plants will need to withstand. There are available considerable amounts of information on winds, waves, and currents enabling such a study for representative oceanic zones where the plants might be located. For each zone a study was conducted of the relevant environmental data, not including temperatures and salinities, which are being inventoried as part of other ocean thermal projects. This study included a literature survey, detailed review of the applicable information, classification of the degree of completeness of the available information, documentation of the available information by preparing circulars or pamphlets for zones and/or sub-zones, generation of additional information for certain locations, and the determination of procedures for obtaining additional data for zones where data are not readily available.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 41

DEFINITION AND SYSTEM PLANNING
Marine Environment

CONTRACTOR & ADDRESS	CONTRACT NO.
U.S. Naval Postgraduate School Monterey, California 39340	ERDA E(49-26)-1044
	PERIOD OF PERFORMANCE April 01, 1976 to Sept. 01, 1977
PRINCIPAL INVESTIGATOR Clarence J. Garrison (408) 646-2632	FUNDING $42,000

TITLE

Dynamic response of moored OTEC plants to ocean waves

SUMMARY

This project is a research program on the interaction of ocean waves with large floating structures and to estimate dynamic response resulting from the wave/structure interaction. The work is not directed toward a particular proposed OTEC plant configuration, but is general and inclusive of several types of OTEC structures under study, and addresses the problems peculiar to mooring large flexible structures in ocean waves.

The research is particularly concerned with the development of a solution for the "fat body" problem of determining open seaway response for objects that do not meet the geometrical assumptions of classical strip theory. New numerical procedures which combine some of the features of the finite element method together with the Green's function method will be studied and adapted to the problem. In addition, the non-linear force which results in slow-drift oscillations is being studied, and analytical methods for its evaluation developed. The work also considers the behavior of the cold-water pipe as it attaches to the OTEC hull structure.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Marine Environment

CONTRACTOR & ADDRESS	CONTRACT NO.
Science Applications, Inc. One Continental Plaza, Suite 310 101 Continental Boulevard El Segundo, California 90245	ERDA E(49-18)-2331
	PERIOD OF PERFORMANCE June 29, 1976 to Sept. 28, 1977
PRINCIPAL INVESTIGATOR Duane T. Hove (213) 640-0480	**FUNDING** $270,000

TITLE
Empirical hydrodynamics studies to produce parameters for determining the drag and lift forces on a cylinder in super-critical flow regimes for OTEC

SUMMARY

Section I:

The first aim of this project is to determine definitive and valid values of drag coefficients, lift coefficients, and Strouhal numbers for long rigid cylinders in uniform flows at Reynolds numbers ranging from 10^6 to 10^7. Data for smooth cylinders and cylinders with surface roughness will be required, as will determination of the effect of low-angle inclination to the flow.

Section II:

Produce a Developmental Experimental Design dealing with methods and apparatus for the acquisition of similar data in a Reynolds number range from 10^7 to 10^8. This is a design project, rather than laboratory work, because the experimental difficulties in this regime are considered to introduce much greater project risk than the work over the range 10^6 to 10^7.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Possible Environmental Impacts

CONTRACTOR & ADDRESS	CONTRACT NO.
U.S. Naval Research Laboratory 4555 Overlook Avenue Washington, D.C. 20375 SUBCONTRACTORS: Science Applications, Inc. and Northwestern University	ERDA E(49-26)-1005
	PERIOD OF PERFORMANCE March 06, 1975 to March 05, 1977
PRINCIPAL INVESTIGATOR Steve A. Piacsek (202) 767-3067	FUNDING $455,200

TITLE
Theoretical fluid dynamical studies of resource availability and environmental impact of ocean thermal power plants

SUMMARY
Exploitation of ocean thermal energy conversion will involve the extraction of heat from the oceans through the circulation and redistribution of very large quantities of warm ocean water from near the surface and cold ocean water from depth. The need to circulate such large quantities of seawater results from the low cycle efficiency associated with the small temperature difference between the warm and cold waters. Local and widespread implementation of this technology could create possible environmental impacts on the ocean and its surroundings. This project identifies such impacts, the availability and replenishment of the thermal resource, and possible climatic effects. Extensive numerical simulations will be made relying on a broad range of modeling techniques available from geophysical fluid dynamics. The work will be pursued somewhat concurrently by studying the following:

1) near-field flow computations, that is adaptation of existing turbulent wake computer programs, production runs for different design parameters, and oceanic data parameters,

2) far-field effects of a single power plant, development of 1-D and 2-D ocean models, determination of optimal power plant size, and areal requirements,

3) oceanic impact of large-scale operation, model temperature, salinity profiles, their time response for various ocean basins, and estimated power production potentials, and

4) air-sea coupling, such as weather-induced thermocline modifications and recovery, and regional sea breeze modification by sea-surface temperature changes. An important aspect of this study is to consider and avoid possible recirculation of spent seawater back to the warm water intakes.

PUBLICATIONS AVAILABLE
See Bibliography Reference 44

DEFINITION AND SYSTEM PLANNING
Possible Environmental Impacts

CONTRACTOR & ADDRESS	CONTRACT NO.
Hydronautics, Inc. 7210 Pindell School Road Laurel, Maryland 20810	ERDA E(49-18)-2348
	PERIOD OF PERFORMANCE May 26, 1976 to May 25, 1977
PRINCIPAL INVESTIGATOR T. R. Sundaram (301) 776-7454	**FUNDING** $127,058

TITLE

Experimentally study flow problems related to an Ocean Thermal Energy Conversion power plant

SUMMARY

The principal objective of this work is to investigate experimentally the external flow problems unique to OTEC, with major emphasis on the recirculation problem. The work will define the conditions for recirculation. There are presently no accurate measurements of these complex flow phenomena to verify their mathematical representation.

A secondary objective is to develop a data base of accurate measurements by which a mathematical model may be verified and its empirical coefficients gleaned. The experiments are designed to isolate each physical mechanism for ease of testing and simplicity of data analysis. A step-by-step testing procedure is followed in which flow parameters are adjusted to more or less isolate phenomena one at a time.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Possible Environmental Impacts

CONTRACTOR & ADDRESS	CONTRACT NO.
Massachusetts Institute of Technology 77 Massachusetts Avenue Cambridge, Massachusetts 02139	ERDA E(11-1)-2909
	PERIOD OF PERFORMANCE Jan. 01, 1976 to March 31, 1977
PRINCIPAL INVESTIGATOR Gerhard H. Jirka (617) 253-6595	FUNDING $79,933

TITLE

External fluid mechanics of ocean thermal power plants

SUMMARY

Determination of the external fluid mechanism of ocean thermal power plants is important for ascertaining the availability of the thermal gradient resource and for the assessment of potential environmental effects. This research program on external fluid mechanics consists of experimentation (70% of effort) and mathematical modeling (30% of effort). The experimental program is aimed at the simulation of the OTEC operation under schematic oceanographic and plant design conditions. The effect of the governing parameters on recirculation is being investigated in a series of experiments conducted in a laboratory basin. The data collected in the testing program are serving for verification and calibration of mathematical (analytical or numerical) models of OTEC operation. The mathematical modeling consists of the development of "zone models" for the distinct hydrodynamic fluid regions which develop during OTEC operation. Combination of the "zone models" yield a predictive tool for engineering studies of the major design and oceanographic parameters, and provide a basis for the interpretation of the experimental data and their extrapolation beyond the parameter range simulated in the experimental program. This research is intended to complement the current research effort on "complete (numerical) modeling" at the U.S. Naval Research Laboratory by providing data (both experimental data and predictions of "zone models") for the verification and calibration of computer codes.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Thermal Resource Assessment and Siting Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Hawaii, University of 2565 The Mall Honolulu, Hawaii 96822	NSF Grant GI-43768
	PERIOD OF PERFORMANCE June 17, 1974 to Aug. 16, 1975
PRINCIPAL INVESTIGATOR Karl H. Bathen (808) 948-8100	FUNDING $48,600

TITLE

Near-shore application for Ocean Thermal Energy Conversion pilot plant in Hawaii

SUMMARY

The purpose of this research is to assess potential sites in Hawaii for the near-shore application of ocean thermal energy conversion. The Hawaiian Islands are essentially a discrete economic group confronted by an increasingly critical electrical energy shortage. They have environmental, legal, government, and socio-economic characteristics that are amenable to interrelation studies.

Two potentially excellent sites in Hawaii appear appropriate for proof-of-concept experiments in ocean thermal energy conversion. At those sites, an experimental ocean thermal power plant could be located either on the coast or on a near-shore floating platform within one mile of the coastline. An initial evaluation has been made of the available data and literature pertinent to the two sites, followed by selection of the favored or primary site. Next, the historical data pertinent to the coastal near-shore oceanography, socio-economic, and environmental characteristics of this favored location has been comprehensively examined. A limited field effort was conducted to supplement existing data. Finally, the consequences of locating an experimental ocean thermal conversion plant in the chosen area were examined, and all historical, field, and other data were summarized.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 47

DEFINITION AND SYSTEM PLANNING
Thermal Resource Assessment and Siting Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Puerto Rico, University of Dept. of Marine Sciences Mayagüez, Puerto Rico 00708	NSF Grant AER-7500145
	PERIOD OF PERFORMANCE April 25, 1975 to April 25, 1976
PRINCIPAL INVESTIGATOR Donald K. Atwood (809) 892-2482	FUNDING $79,000

TITLE

OTEC: Thermal assessment and environmental impact for a proposed Puerto Rico site

SUMMARY

A potential OTEC site should have the following:

1) a thick near-surface layer of warm water,

2) a rapid thermocline to provide cold water at not too great a depth.

3) year-round mild sea conditions, and

4) enough mass transport in the deeper cold water if warm water is cycled into it.

Available data seem to indicate that a site off Puerto Rico meets these general requirements. Additional data needed to define more accurately the oceanographic conditions at the site were obtained principally from three ocean cruises on which Nansen bottle casts were used to measure temperature, salinity, and amounts of phosphate, silicate, and dissolved oxygen. A hydrographic survey was conducted. Finally, current meters were moored at two sites to be retrieved after two 3-month intervals. The resulting data defines the extent of the resource and the prevailing oceanographic conditions, as well as giving an indication of effects resulting from redistribution of salinity, temperature, and selected nutrients.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 48

DEFINITION AND SYSTEM PLANNING
Thermal Resource Assessment and Siting Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Ocean Data Systems, Inc. 6000 Executive Blvd. Rockville, Maryland 20852	NSF C-1020
	PERIOD OF PERFORMANCE May 27, 1975 to May 27, 1976
PRINCIPAL INVESTIGATOR Paul M. Wolff (408) 649-1133	**FUNDING** $93,000

TITLE

OTEC resource, ecological, and environmental studies

SUMMARY

The primary goal of this research was the assessment of the continental shelf areas of the United States for potential sites for installation of ocean thermal power plants. Ideally, such a site should possess the following:

1) a thick layer of near surface warm water,
2) an adequate thermocline to provide cold water at not too great a depth,
3) mild sea conditions, and
4) enough mass transfer at depth to handle input of warm water.

Detailed temperature-salinity-hydrographic data were gathered to assist in the selection of these sites. This project was designed to use existing data on temperature and depth salinity and current to pick favorable sites and map in detail the temperature and current profiles for the sites. Both horizontal and vertical energy potentials were investigated. All detailed profiles were plotted for each of the four seasons of the year. In addition, the work involved a study of selected physical hazards (waves, swell, fog, and hurricanes) which may affect an energy-producing facility. Data for this project were collected primarily from the National Oceanographic Data Center and the Fleet Numerical Weather Central.

From all the above considerations it was concluded that many open-ocean areas at lower latitudes have good potential from an environmental viewpoint, but are not easily accessible logistically. The study identifies the most favorable sites for prototype OTEC installation to be:

1) in the Florida Straits;
2) off the Island of Hawaii;
3) off Puerto Rico.

The study suggests further work in the following areas:

1. Computation of the wave energy spectrum which will be encountered at each site.
2. Computation of the ocean current structure that can be expected around each site using hydrodynamic/numerical models with real bathymetry and tidal/atmospheric driving forces.
3. Refinement of the expected thermal structure, accompanied by engineering computations of environmental effects due to warm water intake, cold-water intake and modified water discharge.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 49

DEFINITION AND SYSTEM PLANNING
Legal and Institutional Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
American Society of International Law 2223 Massachusetts Avenue, N.W. Washington, D.C. 20008	NSF Grant AER-7500280
	PERIOD OF PERFORMANCE Feb. 05, 1975 to July, 1976
PRINCIPAL INVESTIGATOR Robert E. Stein (202) 265-4313	**FUNDING** $83,700*

TITLE

Ocean Thermal Energy Conversion: Legal considerations

SUMMARY

This study identified subjects of needed inquiry within at least five broad areas: rights to emplace and maintain installations; rights to capture and remove the resource; sources and content of legal standards governing emplacement and operation; questions of responsibility and liability for the consequences of operation; and the juridical status of operators and installations. The project examined each of these areas in light of several key variable factors, including the features of the system in place, the environmental consequences of its operation, the likely locations and operators of installations, and the impact of the developing international law of the sea.

An interdisciplinary panel was established to pursue these inquiries in the context of evolving technology for ocean thermal conversion. Its findings were communicated to investigators concerned with other aspects of the technology at a public workshop.

*This amount includes $23,000 provided to NSF by ERDA to support a workshop on "Legal, Political and Institutional Aspects of Ocean Thermal Conversion" held in Washington, D.C. on January 15-16, 1976.

PUBLICATIONS AVAILABLE

DEFINITION AND SYSTEM PLANNING
Legal and Institutional Studies

CONTRACTOR & ADDRESS	CONTRACT NO.
Southern California, University of University Park Los Angeles, CA 90007	NSF Grant AER-7518279
	PERIOD OF PERFORMANCE July 01, 1975 to December 31, 1976
PRINCIPAL INVESTIGATOR Jack M. Nilles (213) 746-7464	FUNDING $122,000

TITLE

Evaluation of incentives for the development of ocean thermal gradient exchange technology

SUMMARY

This research is investigating the kinds and probable effectiveness of incentives to energy producers for the development of ocean thermal gradient exchange (OTGE) technology on a commercial scale. Where the OTGE technology fails to be competitive with fossil fuel energy production, analyses will be made to determine the conditions under which effective competition can occur. This analysis will include evaluations of both economic and non-economic costs and benefits. Alternative public policy options required for proper development of OTGE technology will then be formulated and evaluated. Emphasis will be placed on assessing the probable relative effectiveness of four types of incentives: subsidies, tax benefits, legal constraints and penalties.

The purpose of the research is to identify and evaluate incentives that would directly assist in accelerating the commercialization of OTEC and over which there might be government influence. Included in the research tasks are an investigation of the energy industries' decision-making criteria; an estimate of the economic competitiveness of OTEC with fossil fuel and nuclear power plants; an assessment of indirect benefits of OTEC; and development of policy recommendations for accelerated commercialization.

Although OTEC technologies provide the focus of the research, the recommendations will be largely applicable to other alternative, capital-intensive sources of energy. Such technologies would include geothermal, photovoltaic, solar-thermal, and bioconversion plants.

The final report of the project will be designed to provide public policy makers with specific recommendations which will describe and discuss the requirements for and the necessary extent of government participation in developing OTEC technology.

PUBLICATIONS AVAILABLE

ENGINEERING DEVELOPMENT
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Lockheed Missiles & Space Co., Inc. P.O. Box 504 Sunnyvale, California 94088 SUBCONTRACTORS: *(cf. list in footnote)	ERDA E(04-3)-1291
	PERIOD OF PERFORMANCE June 1, 1976 to October 1, 1976
PRINCIPAL INVESTIGATOR Lloyd C. Trimble (408) 742-5035	**FUNDING** $250,000

TITLE

OTEC tube and shell heat exchanger producibility study

SUMMARY

This project is to conduct a producibility study of shell and tube heat exchangers for an Ocean Thermal Energy Conversion (OTEC) plant. Its purpose is to design the requirements and develop materials information, including the use of concrete, prerequisite to the conceptual and preliminary design of a shell and tube heat exchanger. This study develops design requirements and prepares design concepts. Structural loads during operations are defined and considered. A construction analysis is to be made based upon its concepts through contracts and discussions with three or more large scale heat exchanger manufacturers. Also, design requirements are to be established for a maintenance and repair philosopy for its designs. The results of the study will be made available to interested parties.

*SUBCONTRACTORS: Bechtel Corporation, T. Y. Lin International, Wyatt Industries, Aluminum Company of America (ALCOA Research Center), Yuba Heat Transfer Corporation, University of Denver, Maxwell Laboratories.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Carnegie-Mellon University Dept. of Chemical Engineering Schenley Park Pittsburgh, Pennsylvania 15213 SUBCONTRACTOR: Aluminum Company of America	ERDA E(11-1)-2641
	PERIOD OF PERFORMANCE April 07, 1975 to June 30, 1976
PRINCIPAL INVESTIGATOR Robert R. Rothfus (412) 621-2600, Ext. 325	FUNDING $165,915

TITLE

Concurrent studies of enhanced heat transfer and materials for ocean thermal exchangers

SUMMARY

This project is a collaborative effort by Carnegie-Mellon University and the Aluminum Company of America aimed at reducing the potential costs of heat exchangers being designed for use in ocean thermal power plants and for comparable bottoming-cycle applications. The Carnegie-Mellon part of the study experimentally determines the feasibility of markedly augmenting heat transfer in vertical-tube evaporators and condensers by means of axially fluted surfaces. The ALCOA part experimentally examines the extent to which augmentation may be limited by practical materials problems in the marine environment.

Heat transfer experiments at Carnegie-Mellon were directed toward establishing the level of enhancement and the conditions for peak efficiency in systems involving water and working fluids such as ammonia and a substituted methane. Static and dynamic tests at ALCOA examined corrosion characteristics of aluminum alloys in relation to seawater and working fluids. Mutual reviews of potential heat exchanger designs and of attendant scaling problems were an integral part of the program.

Results indicate that an overall heat transfer coefficient of 900 Btu/hr sq ft degree F can be obtained on a clean axial-fluted surface. Substantial increase in water side heat transfer coefficient can also be achieved in the range of low Reynolds number without additional penalty in pumping power.

Untested projections of prior data indicated that especially large savings are possible if flutes can be formed from extrudable material such as aluminum and if ammonia can be used as the working fluid. These experiments are for establishing whether that combination is a viable base point for economic evaluations of full-scale heat exchanger designs.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 53

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Carnegie-Mellon University Dept. of Chemical Engineering Pittsburgh, Pennsylvania 15213	ERDA E(11-1)-2641 – Continuation
	PERIOD OF PERFORMANCE August 1, 1976 to July 30, 1977
PRINCIPAL INVESTIGATOR Robert R. Rothfus (412) 621-2600, Ext. 325	**FUNDING** $399,829

TITLE

Studies of enhanced heat transfer for ocean thermal exchangers

SUMMARY

This work is a continuation of previous experimental activities. The experiments will simulate certain critical conditions in the water and ammonia systems known to exist in an OTEC heat exchanger. The bulk of the effort is concerned with fluid management and manifolding problems associated with large volumetric flows of OTEC heat exchangers. The work will include conducting a literature search on the current state-of-the-art on vertical tube evaporator design, with emphasis on the following:

a) Thermal hydraulic design method used

b) Problem areas leading to malfunctioning

c) Identification of problems for advancing the current state-of-the-art

d) Recommendation of future heat exchanger studies to be undertaken by ERDA-OTEC

The literature survey will focus on international heat transfer literature as published in various periodicals and journals as well as patent literature.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Oak Ridge National Laboratory (ORNL) P.O. Box X Oak Ridge, Tennessee 37830	ERDA W-7405-eng-26
	PERIOD OF PERFORMANCE May 01, 1976 to Sept. 30, 1976
PRINCIPAL INVESTIGATOR H. W. Hoffman (615) 483-8611, Ext. 37715	**FUNDING** $192,000

TITLE

Heat transfer enhancement for OTEC systems

SUMMARY

This study explores means for enhancing the boiling and condensing performance of heat exchangers for service in OTEC systems. Emphasis is being placed on the study of ammonia condensation on Gregorig surfaces. The initial period of this study includes design and assembly of laboratory scale apparatus for condensing studies with ammonia, determination of concept feasibility through scoping experiments, and design of a more flexible facility for characterization of optimum configurations.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Geoscience, Ltd. 410 S. Cedros Avenue Solana Beach, California 92075	ERDA E(04-3)-1094
	PERIOD OF PERFORMANCE May 01, 1975 to April 30, 1977
PRINCIPAL INVESTIGATOR Cullen M. Sabin (714) 755-9396	FUNDING $145,000

TITLE

Water heat transfer and ammonia nucleate studies

SUMMARY

The continuation of the project consists of two separate investigations:

(1) Water-side heat transfer coefficient enhancement, and

(2) Nucleate boiling

Early results have shown that the water-side coefficient can be increased in the region of low Reynolds number without increase in pumping power requirements. These results were obtained with different kinds of wire inserts inside the tube. Nucleate boiling studies with ammonia have shown that nucleation can be achieved with a temperature difference of 0.2°F with wire mesh screens wrapped around the tubes.

Work is being continued on optimizing the different geometries for the water-side enhancement and establishing the stability of nucleation under multiple start-up conditions over a long time period.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 56

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Union Carbide Corporation Linde Division Oak Ridge National Laboratories P.O. Box 4 Oak Ridge, Tennessee 37830	NSF Grant GI-43441
	PERIOD OF PERFORMANCE June 25, 1974 to March 24, 1975
PRINCIPAL INVESTIGATOR Frank Notaro (716) 877-1600, Ext. 8122	**FUNDING** $93,200

TITLE

Heat exchangers for ocean thermal power plants

SUMMARY

This study was to define cost performance characteristics of heat exchangers for use in OTEC systems. These cost performance characteristics are required as inputs to cost analysis and optimization studies. In this study, conceptual designs of both evaporators and condensers for ocean thermal power plants were developed. For each concept and therefore for each cost estimate, analytical data were generated indicating the amount of heat which the heat exchanger will transfer, the water pumping power required to produce the heat transfer, and thermodynamic penalties on the power cycle (working fluid pressure drops). Heat exchanger concepts considered various geometries, several fluid arrangements (e.g., power fluid tube or shell side), state-of-the-art and innovative heat transfer technology in evaporating, condensing and water-side service, various materials of construction, and an assessment of the possible effects of biological fouling or erosion.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 57

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Union Carbide Corporation Linde Division/Branch 4019451 P.O. Box 44 Tonawanda, New York 14150	ERDA E(49-18)-2448
	PERIOD OF PERFORMANCE June 30, 1976 to June 30, 1977
PRINCIPAL INVESTIGATOR Frank Notaro (716) 877-1600, Ext. 8122	**FUNDING** $426,000

TITLE

Heat exchangers for ocean thermal power plants

SUMMARY

This study is to investigate the thermal hydraulic performance of the heat exchanger, with special emphasis on the evaporator. The study is being focused on assessing the baseline design as proposed by Lockheed and further evaluate the methods for reducing the overall cost of the heat exchanger via enhancement of the heat transfer coefficient. The study is divided into six main task categories:

1) performance studies of a flooded evaporator,

2) heat transfer study,

3) performance studies of a large spray film evaporator,

4) experimentally demonstrate the thermal hydraulic performance of the heat exchanger,

5) physical design and manufacturing cost, and

6) life and reliability of the heat exchanger.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Applied Physics Laboratory Johns Hopkins University (APL-JHU) VIA: Naval Sea Systems Command (NAVSEA) Department of the Navy Code: SEA-0253W Arlington, Virginia 20360	ERDA E(49-26)-1030
	PERIOD OF PERFORMANCE June 27, 1975 to Nov. 10, 1975
PRINCIPAL INVESTIGATOR H. Lowell Olsen (301) 953-7100, Ext. 7469	**FUNDING** $32,100

TITLE

Analytical study of two-phase-flow heat exchangers for OTEC systems

SUMMARY

This study was a detailed analysis of the practicality and expected performance of the APL-JHU concept for two-phase-flow heat exchangers for an ocean thermal energy conversion (OTEC) power plant. In this concept, the working fluid would flow on the inside of large-diameter (3 in. to 9 in.) multipass tubes. The analytical model for the heat exchangers was based upon the latest two-phase-flow theory and correlations. Parametric studies for producing heat exchanger designs (for the evaporator and condenser) were used to project minimum annual costs (including amortization and expected operating, maintenance, repair and replacement costs) over the equipment lifetime. The work included development of a power module design for use within an overall power plant concept incorporating manifolding/assembly/disassembly, as well as the design of an experiment that could provide engineering data on both evaporator and condenser performance.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Applied Physics Laboratory Johns Hopkins University (APL-JHU) VIA: Naval Sea Systems Command (NAVSEA) Department of the Navy Code: SEA-0253W Arlington, Virginia 20360	ERDA E(49-26)-1030
	PERIOD OF PERFORMANCE April 20, 1976 to February 20, 1977
PRINCIPAL INVESTIGATOR Robert Makofski (301) 953-7100, Ext. 7494	**FUNDING** $137,000

TITLE

Experimental studies of two-phase-flow heat exchangers for OTEC systems (Phase I)

SUMMARY

This study includes preliminary experiments on the flow and heat transfer in the two-phase-flow heat exchangers using two models. The first, simulating a portion of an evaporator tube, is being used for internal flow experiments to

1) perform an evaluation of potential dry-out problem,

2) validate heat transfer coefficients, and

3) determine pressure losses in return bends.

The second model is being used to determine circumferential distribution of the water-side heat transfer coefficient on one tube in simulated tube arrangement and to check water pressure drop and evaluate the degree of water crossflow through the arrangement.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers/Biofouling

CONTRACTOR & ADDRESS	CONTRACT NO.
Hawaii, University of 2565 The Mall Honolulu, Hawaii 96822 SUBCONTRACTOR: Applied Physics Laboratory, Johns Hopkins University	NOAA Office of Sea Grant 04-5-158-44026
	PERIOD OF PERFORMANCE May 20, 1976 to December 31, 1976
PRINCIPAL INVESTIGATOR James H. Jones (808) 948-8745	**FUNDING** $53,591 (plus matching funds from the state of Hawaii of $65,791)

TITLE

OTEC heat exchanger biofouling experiment

SUMMARY

1. To observe the biofouling rate in tropical water typical of a tropical ocean site and APL heat exchanger water flow conditions.

2. To measure water side heat transfer coefficients under hydrodynamic conditions duplicating those of the APL heat exchanger (V_W = 3-7 ft/sec)

   a. As a function of fouling time and
   b. After cleaning with a high-pressure water-jet system.

3. Optionally, to observe the effect on biofouling of a different tube arrangement (pitch ratio) and/or darkness.

4. To determine the magnitude of microbial fouling of the heat exchangers

   a. By direct microscopic examination of materials accumulating on the pipe surface
   b. By photographic recording of the material for later, more convenient identification of larger forms.
   c. By survey of the types of facterial forms by culture techniques.

5. Quantification of microbial fouling organisms.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
DSS Engineers, Inc. 7483 Northwest 4th Street Fort Lauderdale, Florida 33317	NSF Grant GI-43444
	PERIOD OF PERFORMANCE May 31, 1974 to Feb. 28, 1975
PRINCIPAL INVESTIGATOR W. B. Suratt (305) 792-6660	**FUNDING** $59,900

TITLE

Development of plastic-tubed heat exchangers for sea solar power plants

SUMMARY

The objective of the research was to investigate, in depth, the technical and economic feasibility of utilizing plastic-tubed heat exchangers in an ocean thermal power plant. Since heat exchangers may represent about one-half of the capital costs of such a plant, this study attempted to demonstrate that plastic-tubed heat exchangers are well suited for such an application, and that substantial cost savings can be achieved through their use.

The investigation involved several tasks. The largest effort concentrated on the technical problems and economics of fabricating large plastic-tubed heat exchangers. Experimental work was conducted off the Florida coast, using samples of candidate plastic-tubing materials and of various metallic alloys to determine relative growth rates of marine organisms. Laboratory tests were performed to determine the compatibility of the plastic materials with proposed working fluids.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 62

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
DSS Engineers, Inc. 7483 Northwest 4th Street Fort Lauderdale, Florida 33317	ERDA E(40-1)-5165
	PERIOD OF PERFORMANCE Aug. 1, 1976 to Sept. 30, 1978
PRINCIPAL INVESTIGATOR William R. Suratt (305) 792-6660	**FUNDING** $320,241

TITLE

Development of plastic-tubed heat exchangers

SUMMARY

This continuation of the earlier study provides an in-depth review of polymeric materials and material composites that have been proposed for the plastic heat exchangers. Test apparatus is to be designed to achieve accurate and significant tests for predicting long-term durability of plastic heat exchangers in an OTEC environment. The polymer samples are to be given screening tests to

1) determine the complete set of tensile properties,

2) rank the various types of a given polymer with regard to susceptibility to environmental stress-cracking,

3) eliminate the most unsuitable materials or to indicate some degree of relative ranking of the materials to chemical resistance by using ammonia or other OTEC working fluids, and

4) evaluate the polymers selected by the screening tests under conditions simulating the OTEC heat exchanger.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 62

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Oklahoma, University of School of Chemical Engineering and Materials Sciences 202 W. Boyd, Room 23 Norman, Oklahoma 73069	1. NSF Grant AER-7500022 2. ERDA E(40-1)-4918
	PERIOD OF PERFORMANCE 1. June 25, 1975 to June 24, 1976 2. Aug. 15, 1976 to Aug. 14, 1977
PRINCIPAL INVESTIGATOR Kenneth E. Starling (405) 325-5811	**FUNDING** 1. $49,814 2. $54,159

TITLE

Use of mixtures as working fluids in ocean thermal energy conversion cycles

SUMMARY

The NSF research project consisted of:

1) evaluation of the advantages and disadvantages of the use of mixtures as working fluids in ocean thermal energy conversion power cycles,
2) development of a computer program capable of simulating ocean thermal power cycles employing both mixtures and pure working fluids,
3) development of an accurate thermodynamic properties computer program package (applicable as a minimum to hydrocarbon mixtures and pure fluids),
4) comparison of mixture and pure fluid cycles including relative equipment sizing and economics,
5) comparison of boiling and condensing heat transfer for mixtures and pure fluids, and
6) evaluation of the advantages and disadvantages of turbine expansion into the two-phase region.

The use of mixtures in ocean thermal power cycles was evaluated for hydrocarbon mixtures, ammonia-water mixtures and possible halocarbon mixtures. The mixtures cycles were compared with baseline pure fluid ocean thermal power cycles using propane, ammonia, and possible halocarbons as working fluids.

The ERDA research project of the overall research program includes the following elements:

1) upgrading of the Phase I OTEC mixture cycle simulator (particularly the condenser design subroutine to include the effects of diffusive mass transfer),
2) development of an optimization program for OTEC mixture cycle optimized design,
3) correlation of the thermodynamic properties of ammonia-water mixtures for ranges of conditions applicable to OTEC cycles,
4) simulation of the OTEC ammonia cycle with varying amounts of water in the ammonia to provide information on the ammonia-water cycle and determine the maximum tolerable water concentration for acceptable thermodynamic performance of the cycle,
5) evaluation of alternative cycles using the optimization program developed in this research.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 64

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR & ADDRESS	CONTRACT NO.
Oklahoma State University School of Chemical Engineering Stillwater, Oklahoma 74074	ERDA E(40-1)-5092 NSF Grant AER-75-04480
	PERIOD OF PERFORMANCE Nov. 21, 1975 to Jan. 31, 1977
PRINCIPAL INVESTIGATOR Kenneth J. Bell (405) 624-5280	**FUNDING** $66,000

TITLE

Heat exchanger system evaluation for the OTEC program

SUMMARY

The technical and economic feasibility of the OTEC concept is dependent upon the heat exchangers which dominate the cost, size, configuration and operation reliability of the plant. To help bring current information to bear on OTEC heat exchanger design, and so that new concepts are evaluated as quickly as possible, this project undertakes the following:

1) helps maintain the overall schedule for OTEC research, development, and deployment,

2) identifies areas of heat transfer technology in which exchanger system design methods and operating experience exist in large scale process plants and are applicable to ocean thermal power plants,

3) develops procedures to ensure that system analysts be supplied with pertinent heat exchanger design and operational parameters, and

4) performs "quick-look" analysis and evaluation on any variation in heat exchanger system configuration that seems to show promise for improvements in OTEC plant construction or operation.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 65

ADVANCED RESEARCH AND TECHNOLOGY
Exploratory Power Cycles

CONTRACTOR & ADDRESS

Carnegie-Mellon University
Dept. of Physics
Schenley Park
Pittsburgh, Pennsylvania 15213

CONTRACT NO.

ERDA E(11-1)-2768

PERIOD OF PERFORMANCE

June 09, 1975 to February 29, 1976

PRINCIPAL INVESTIGATOR

John G. Fetkovich
(412) 621-2600, Ext. 484

FUNDING

$27,178

TITLE

Study of a foam closed-cycle solar sea power plant

SUMMARY

This project was to determine the feasibility of a foam ocean thermal power cycle. The study consisted of experiments to examine techniques for generating foam of sufficient stability. Methods of foam generation examined included nucleation of very small bubbles and injection of vapor into rising liquid. A principal experimental objective was to determine whether a stable foam can be raised at a rate within an order of magnitude of that corresponding to the theoretical maximum power calculated neglecting losses. Foam flow, stability and separation were studied experimentally. A working model of a complete foam system was constructed. Biological studies were conducted to explore the interactions between the biological environment, organic matter in sea water, and the foaming properties of sea water.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 66

ADVANCED RESEARCH AND TECHNOLOGY
Exploratory Power Cycles

CONTRACTOR & ADDRESS	CONTRACT NO.
U.S. Naval Construction Battalion Center Civil Engineering Lab. (CEL) Port Hueneme, Calif. 93043	U.S. Navy Civil Engineering Laboratory internal research
	PERIOD OF PERFORMANCE July 01, 1975 to Dec. 30, 1975
PRINCIPAL INVESTIGATOR Earl J. Beck*	**FUNDING** $25,000

TITLE

Nucleation of steam bubbles for a proposed ocean thermal gradient hydraulic power plant

SUMMARY

This effort was an experimental and analytical study into the feasibility of an OTEC power cycle utilizing the nucleation of steam bubbles. This idea provided the basis for a patent disclosure processed by the Office of Naval Research and resulting in Patent 3,967,449, which was abstracted in the July 6, 1976 *Patent Gazette*. The work was done in four steps:

1) Literature search;

2) Experiment design;

3) Construction and test;

4) Drafting of a report.

The experiment was exploratory, to demonstrate the possibility of building a stream lift pump, analogous to an air lift pump. The pending report summarizing this project describes Mr. Beck's concept of the nature of nucleation (cavitation) of steam bubbles, the experimental results, and discusses the prospects for application of the steam lift pump to ocean thermal energy conversion. Besides the steam lift pump, an ocean thermal gradient hydraulic power plant would also include a spray or contact condenser and a Taylor air compressor.

*Mr. Beck retired from the U.S. Civil Service at the end of 1975. He is currently pursuing this research under the auspices of Design Services, 998 Church Street #27, Ventura, California 93001, telephone (805) 643-7331.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Submarine Electrical Cables

CONTRACTOR & ADDRESS

Little, Arthur D., Inc.
Physical Systems Section
28 Acorn Park
Cambridge, Mass. 02140

CONTRACT NO.

NSF C-1019

PERIOD OF PERFORMANCE

May 01, 1975 to April 30, 1976

PRINCIPAL INVESTIGATOR

James Nicol
(617) 864-5770

FUNDING

$50,200

TITLE

A study of electrical energy transmission for ocean thermal power plants

SUMMARY

This study provides an analysis of the utilization of electrical power transmission as an alternative for transporting energy from large-scale floating ocean thermal energy conversion plants to wholesale energy markets. In particular, the study analyzes the technical and economical viability of electrical power transmission cables and systems in which both AC and DC power systems are considered. These systems are:

(1) oil impregnated paper insulation cable,

(2) synthetic paper insulated cable,

(3) extruded dielectric cable, and

(4) gas (SF_6) insulated cable.

The use of multiple circuits is also being considered for a more reliable operation. Transmission costs and the deliverable power as a function of a representative profile of the sea bottom are being calculated. Transmission costs are to be optimized to determine the most economical system. Comparisons between electrical transmission systems and hydrogen transmission systems are being undertaken. The study also includes recommendations for needed R&D in the various subsystems.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 68

ADVANCED RESEARCH AND TECHNOLOGY

Biofouling and Corrosion

The proejcts in biofouling and corrosion summarized on the following eight pages are under the management of Battelle Pacific Northwest Laboratories (PNL).

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling and Corrosion

CONTRACTOR & ADDRESS

Carnegie-Mellon University
Dept. of Physics
Schenley Park
Pittsburgh, Penn. 15213

SUBCONTRACTOR: University of Hawaii

CONTRACT NO.

NSF AER-7500025

PERIOD OF PERFORMANCE

May 15, 1975 to May 14, 1976

PRINCIPAL INVESTIGATOR

John G. Fetkovich
(412) 621-2600, Ext. 484

FUNDING

$160,100

TITLE

A study of fouling and corrosion problems in a solar sea power plant

SUMMARY

This project was aimed at establishing the limits within which scaling, biofouling, and corrosion can be held in check for the life of an OTEC power plant without adding excessively to capital or operating costs. The objectives were to determine the best heat exchanger material, means for inhibiting biological growth, and to provide experimental data on biofouling and corrosion necessary for the design of a complete OTEC power plant.

A program of laboratory research was carried out at Carnegie-Mellon University, including studies of the corrosion properties of heat exchanger tubing materials and investigation of techniques for the laminar layer injection of chlorine and heavy-metal ions into the heat exchanger flow stream. Instrumentation was developed in the laboratory for installation in the ocean environment off Ke-Ahole Point, Hawaii. Field tests were conducted in cooperation with the University of Hawaii at a site in the open ocean off the windward coast of the island of Oahu at depths in the order of 100 feet.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 70

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling and Corrosion

CONTRACTOR & ADDRESS	CONTRACT NO.
Carnegie-Mellon University Schenley Park Pittsburgh, Pennsylvania 15213 SUBCONTRACTOR: University of Hawaii	Battelle PNL AT(45-1)-1830
	PERIOD OF PERFORMANCE May 15, 1976 to February 14, 1977
PRINCIPAL INVESTIGATOR John G. Fetkovich (412) 621-2600, Ext. 484	**FUNDING** $191,217 + $40,324

TITLE

A study of fouling and corrosion problems in a solar sea power plant

SUMMARY

The objectives of this project are:

1. Install the biofouling measuring device in the sea at Ke-Ahole Point and conduct tests.
2. Complete proof testing of the biofouling monitoring device and experimental methods.
3. Compile a comprehensive report, after proof testing, describing in detail the design, construction, testing and operation of the system.
4. Carry out studies of fouling rates in heat exchanger tubes of various materials.
5. Design, construct, test and evaluate a system for bulk chlorination (to be used with the biofouling device).

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling and Corrosion

CONTRACTOR & ADDRESS	CONTRACT NO.
U.S. Naval Construction Battalion Center Civil Engineering Lab. (CEL) Port Hueneme, Calif. 93043	Battelle PNL AT(45-1)-1830
	PERIOD OF PERFORMANCE July 12, 1976 to July 5, 1977
PRINCIPAL INVESTIGATOR James F. Jenkins (805) 982-4797	**FUNDING** $25,000 + $10,000

TITLE

A critical review of the design factors influencing biofouling and corrosion of OTEC system surfaces

SUMMARY

The objectives of this project are:

1. Conduct a literature survey on biofouling and corrosion design.
2. Critically evaluate data and prepare a report.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Control of Biofouling

CONTRACTOR & ADDRESS	CONTRACT NO.
Hydronautics, Inc. 7210 Pindell School Road Laurel, Maryland 20810	Battelle PNL AT(45-1)-1830
	PERIOD OF PERFORMANCE July 19, 1976 to April 15, 1977
PRINCIPAL INVESTIGATOR A. F. Conn (301) 776-7454	FUNDING $64,690

TITLE

Investigation of OTEC heat exchanger cleaning methods

SUMMARY

The objectives of this project are to:

1. Conduct a critical state-of-the-art study of mechanical and chemical cleaning of low-temperature marine heat exchangers.
2. Develop a conceptual method for applying an optional cleaning process to an OTEC heat exchanger.
3. Report on the results of these efforts.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Prevention of Biofouling

CONTRACTOR & ADDRESS

Allied Chemical Corporation
Specialty Chemical Division
P.O. Box 1069
Buffalo, New York 14240

CONTRACT NO.

ERDA E(11-1)-2692

PERIOD OF PERFORMANCE

May 01, 1975 to June 30, 1976

PRINCIPAL INVESTIGATOR

Phillip E. Jones
(716) 824-5000, Ext. 497

FUNDING

$47,250

TITLE

Prevention of biofouling on heat transfer surfaces of ocean thermal energy converters

SUMMARY

The purpose of this study is to determine the feasibility of developing an antibiofouling treatment consisting of monomolecular layers chemically affixed to the surfaces of metallic heat exchangers. This treatment is predicated on the formation of non-wettable, non-adherent, smooth surfaces that are unsuitable for the disposition and accretion of the slime layer that precedes the attachment and growth of fouling organisms and toxic surfaces that are lethal only to the fouling organisms that may adhere. To achieve this effect, the metal surface is modified with a monomolecular layer that is composed of specific hydrophobic fluorochemicals and certain tributyltin based toxicants and chemically affixed to the structural metal of a conversion coating.

This research consists of:

1) preparation of the specific fluorochemicals,

2) treatment of selected metal specimens with various combinations of these fluorochemicals and certain tributyltin based toxicants and

3) exposure to these treated specimens along with the appropriate controls in a fouling-prone marine environment with periodic appraisal of their antifouling performance.

The investigation is expected to generate the preliminary technology that is needed to develop a viable surface treatment aimed at eliminating biofouling on the heat transfer surfaces of ocean thermal power plants without adversely affecting their heat transfer characteristics.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 74

ADVANCED RESEARCH AND TECHNOLOGY
Corrosion of Aluminum

CONTRACTOR & ADDRESS	CONTRACT NO.
Delaware, University of College of Marine Studies Lewes, Delaware 19958 SUBCONTRACTOR: Woods Hole Oceanographic Institute	ERDA E(11-1)-2957
	PERIOD OF PERFORMANCE June 15, 1976 to June 14, 1977
PRINCIPAL INVESTIGATOR Stephen C. Dexter (302) 738-2841	**FUNDING** $52,193

TITLE

Effects of contamination of seawater on aluminum alloys for heat exchangers

SUMMARY

The rate of penetration of aluminum and aluminum alloys by pitting corrosion in the marine environment in the presence or absence of fouling organisms is known to be dependent on the dissolved oxygen content, the concentration of heavy metal contaminants, the temperature, and the velocity of the seawater. It is not possible, however, using existing data to quantitatively predict the lifetime with respect to perforation by pitting of aluminum alloys exposed to natural seawater as a function of the above environmental parameters. In order to fully evaluate the feasibility of using aluminum alloys, as opposed to titanium or polymers, for heat exchanger and condenser tubing in Ocean Thermal Energy Conversion (OTEC) power plants, it is important to be able to make such predictions.

The goal of this project is to develop this predictive capability by using electrochemical techniques to measure the effects of dissolved oxygen concentration and of heavy metal contaminants in quiescent, sterile seawater both on the induction time for pit initiation and on pit growth rates in several commercial aluminum alloys of interest to the OTEC program. The effects of velocity and microfouling organisms are also being investigated.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Corrosion of Aluminum and Titanium

CONTRACTOR & ADDRESS

Sigma Research, Inc.
2952 George Washington Way
Richland, Washington 99352

CONTRACT NO.

Battelle PNL E(45-1)-2446

PERIOD OF PERFORMANCE

Sept. 30, 1976 to Sept. 29, 1977

PRINCIPAL INVESTIGATOR

Elric W. Saaski
(509) 946-0663

FUNDING

$73,783

TITLE

Compatibility studies for the system water-ammonia-titanium as related to ocean thermal energy conversion

SUMMARY

The objectives of this project are:

1. Study the stress corrosion cracking behavior of titanium in ammonia contaminated with seawater.
2. Determine the electrochemical compatibility of titanium with mild steel in liquid ammonia environments.
3. Report the results of their experimental studies.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Corrosion of Aluminum

CONTRACTOR & ADDRESS	CONTRACT NO.
Aluminum Company of America Alcoa Laboratories Alcoa Center, PA 15069	Battelle PNL B-31942-A-E
	PERIOD OF PERFORMANCE Sept. 30, 1976 to April 29, 1977
PRINCIPAL INVESTIGATOR D. G. Reininga (412) 339-6651	**FUNDING** $34,975

TITLE

Catalog information on the performance of aluminum in seawater

SUMMARY

The objectives of this project are:

1. Compile and critically evaluate existing data on the corrosion of aluminum and aluminum alloys in seawater.
2. Prepare a catalog of their data that can be used for OTEC purposes.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY

Ocean Engineering

The projects in ocean engineering summarized on the following nine pages are under the management of the Naval Facilities Engineering Command (NAVFAC), U.S. Department of the Navy.

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Concrete Structures

CONTRACTOR & ADDRESS

Lehigh University
Dept. of Civil Engineering
Bethlehem, PA 18015

CONTRACT NO.

ERDA E(11-1)-2682

PERIOD OF PERFORMANCE

April 25, 1975 to April 24, 1976

PRINCIPAL INVESTIGATOR

Wai-Fah Chen*

FUNDING

$82,730

TITLE

Reinforced concrete constitutive relations

SUMMARY

The investigators had previously done theoretical research enabling them to predict reasonably well the constitutive (stress-strain) relations for concrete under general load conditions, including hydrostatic pressure. This project extended that research to cover reinforced concrete. Hydrostatic pressure at the ocean depths occupied by structural components of ocean thermal power plants is several atmospheres, hence the behavior of materials such as concrete under such conditions may be substantially different from that normally experienced in an air environment. A computer program was developed in the form of a subroutine for incorporating into existing finite element analysis programs, and this program can be made available to structural analysts. The constitutive relations developed are of a general nature, in that the effects of hydrostatic pressure may be either included or neglected in defining the materials response. Thus, they are applicable both for the analysis of submerged ocean structures and on land for underground structures.

*Dr. Chen is now located at the Department of Civil Engineering, Purdue University, W. Lafayette, Indiana 47907, Telephone: (317) 494-5733.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 79

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Concrete Structures

CONTRACTOR & ADDRESS	CONTRACT NO.
U.S. Naval Construction Battalion Center Civil Engineering Lab. (CEL) Port Hueneme, Calif. 93043	ERDA E(49-26)-1023
	PERIOD OF PERFORMANCE May 25, 1975 to Dec. 01, 1976
PRINCIPAL INVESTIGATOR Harvey H. Haynes (805) 982-5578	FUNDING $47,000

TITLE

Design, fabrication, and installation of large diameter submerged concrete structures

SUMMARY

This was a feasibility study of the design, fabrication, and installation of large diameter submerged concrete structures. The state-of-the-art related to these structures was summarized, feasible approaches for fabricating and installing the structures recommended, problem areas enumerated, and research and development areas outlined. The intent of this study was to point out significant problem areas and to assess the feasibility of using large concrete structures for ocean thermal power plants, so as to provide ERDA with some decision criteria on which to focus research and development efforts.

The continuation of this contract is directed toward investigating the properties of lightweight concretes to determine their potential for consideration and utilization in the construction of OTEC hulls and/or structural components.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 80

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Anchor Systems

CONTRACTOR & ADDRESS

U.S. Naval Construction Battalion Center
Civil Engineering Lab. (CEL)
Port Hueneme, Calif. 93043

CONTRACT NO.

ERDA E(49-26)-1017

PERIOD OF PERFORMANCE

May 02, 1975 to Dec. 01, 1976

PRINCIPAL INVESTIGATORS

Robert J. Taylor (805) 982-5419
Philip Valent (805) 982-5780

FUNDING

$139,000

TITLE

Studies of anchor systems for OTEC power plants

SUMMARY

This project was aimed at extending the state-of-the-art in deepsea anchor systems to satisfy the anchor-design requirements of large floating ocean thermal energy conversion power plants. These new requirements result from the difficult combination of environmental conditions, water depth, and large power plant size. The actual performance characteristics of existing anchors were determined. Performance characteristics of enlarged versions of existing anchors were estimated, and innovative anchoring concepts devised and evaluated. This task was accomplished by utilizing experience of the U.S. Navy and of private industry, particularly oil companies and drilling contractors. The capability of each anchor, evaluated according to shear strength, was defined for a series of seafloor site varieties that could be encountered at potential ocean thermal power plant locations. (These site varieties account for the majority of possible seafloors where ocean thermal energy conversion is regarded as practicable.)

Conceptual designs of high strength anchor systems were parametrically devised, by combining high capacity concepts to achieve high holding anchor systems, and by scaling up existing anchor designs.

The continuation of this contract is directed toward technical refinement of the most promising anchor design concepts suited to OTEC and study of anchor fabrication deployment and installation techniques.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 81

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Cold-Water Pipe, Pumps, Mooring

CONTRACTOR & ADDRESS

Westinghouse Electric Corp.
Oceanic Division
P.O. Box 1488
Annapolis, Maryland 21404

CONTRACT NO.

ERDA E(11-1)-2642

PERIOD OF PERFORMANCE

April 07, 1975 to April 07, 1976

PRINCIPAL INVESTIGATOR

Thomas E. Little
(301) 765-5446

FUNDING

$178,000

TITLE

Deep water pipe and mooring design study

SUMMARY

The main thrust of the study is the preliminary evaluation of cold water pipe, pump, and plant mooring concepts, with a view toward judging their effect upon the overall evaluation of the ocean thermal energy conversion concept. Two principal goal criteria guide the selection of areas of concentration:

1) to illuminate the impact of the cold-water transport and mooring systems on the overall power plant concepts,

2) to delineate critical development needs.

The selection of the three subsystems (pipe, pump, and mooring) for combined study is based upon their mutual interrelationship and dependence on common environmental and system parameters. The study identifies a spectrum of possible design concepts, selects one or more alternatives for further evaluation, and assesses them in terms of such criteria as structural characteristics, feasibility of construction and deployment, operating efficiency implications, serviceability, research and development requirements, and cost. Salient conclusions distilled from the concept analyses and their overall plant-concept-evaluation implications are explored. Alternatives are described, and their impacts and interactions as a function of parameters over ranges of interest are shown. Recommendations are made regarding technological directions that should be pursued.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 82

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Cold-Water Pumps

CONTRACTOR & ADDRESS	CONTRACT NO.
Westinghouse Electric Corp. P.O. Box 1488 Annapolis, Maryland 21404	ERDA E(11-1)-4071
	PERIOD OF PERFORMANCE July 1, 1976 to June 30, 1977
PRINCIPAL INVESTIGATOR T. E. Little (301) 765-5446	**FUNDING** $199,901

TITLE

OTEC cold-water pump designs

SUMMARY

This work is to determine whether warm water pump designs can be the same as cold-water pump designs. This determination will have a major bearing on OTEC pump design. It includes preliminary design of a cold-water pump. This is a continuation of work done under a previous OTEC contract. Producibility realities will be introduced through collaboration of Westinghouse Marine Division.

The work includes analyses of various available platform dynamic positioning methods and quantitative tradeoff studies to determine their relative costs and benefits.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Platforms and Cold-Water Pipe

CONTRACTOR & ADDRESS

Hydronautics, Inc.
7210 Pindell School Road
Laurel, Maryland 20810

CONTRACT NO.

ERDA E(11-1)-2681

PERIOD OF PERFORMANCE

April 25, 1975 to April 24, 1977

PRINCIPAL INVESTIGATOR

Roderick A. Barr
(301) 776-7454

FUNDING

$226,000

TITLE

Studies of seaway responses of OTEC platform/cold-water pipe configuration—effects of pipe elasticity and model tests

SUMMARY

This project, originally entitled "Evaluation of Platform Designs for Ocean Thermal Power Plants," consisted of an evaluation of sea keeping (motions and accelerations), junction loads, cold-water pipe bending moments, and stationkeeping thrust requirements for five unmoored candidate platform types each with a cold-water pipe or riser for ocean thermal power plants. The study is designed to provide information necessary to indicate which platform types appear most attractive.

The study developed a mathematical model of sea keeping response that employed linear wave theory with a Piereon-Maskawitz representative of the sea spectrum for three sea states. It was conducted in a parametric sense with respect to plant output (size), cold-water pipe length, diameter and degree of fixity at the hull (the pipe itself was assumed infinitely stiff), and platform heading into oncoming waves.

The platform shapes chosen for investigation are: the semisubmersible, ship shape, disc, spar, and submersible.

The continuation study will determine in detail the probable effects of cold-water pipe stiffness on OTEC platform design and develop design tools needed for optimum design on platforms/pipe configurations. The study will

1) define the elastic properties of typical pipe designs,

2) develop new methods for calculation of platforms/pipe dynamics and loads, and

3) use these methods to calculate the dynamic seaway induced motions and loads.

Using this data, two platform/pipe configurations will be selected for hydraulic model testing, two models constructed and tested, and the test results compared with predicted responses from the earlier developed mathematical representation.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 84

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Platforms and Cold-Water Pipe

CONTRACTOR & ADDRESS	CONTRACT NO.
Hydronautics, Inc. 7210 Pindell School Road Laurel, Maryland 20810	ERDA E(49-18)-2424
	PERIOD OF PERFORMANCE April 29, 1976 to October 28, 1976
PRINCIPAL INVESTIGATOR Pin Yu Chang (301) 776-7454	FUNDING $35,000

TITLE

Structural analysis and design studies of OTEC cold-water pipe

SUMMARY

This study is developing a methodology for structural design of OTEC cold-water pipe. Differential equations are being developed including factors neglected in simple beam theory, e.g., variable axial force, non-linearity, variable cross section, shear deflections, and load changes due to local deformations in parametric fashion. The equations are being subjected to parametric analysis various loads, configurations, and materials. Instability due to hydroelastic instability is being studied and an analysis is being made of fatigue strength. The structural design of the cold-water pipe is heavily influenced by the seakeeping parameters detailed in Hydronautics' seaway response model.

PUBLICATIONS AVAILABLE

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Cold-Water Pipe

CONTRACTOR & ADDRESS	CONTRACT NO.
Sea Solar Power, Inc. 1615 Hillock Lane York, Pennsylvania 17403	ERDA E(11-1)-2691
	PERIOD OF PERFORMANCE April 21, 1975 to February 21, 1976
PRINCIPAL INVESTIGATOR J. Hilbert Anderson (717) 741-0884	FUNDING $39,100

TITLE

Design of a cold water pipe for ocean thermal power plants

SUMMARY

This project was to assess the feasibility of the stockade pipe concept for application to the cold-water intake requirements of floating ocean thermal power plants. A large diameter pipe (12 meters or greater) comprised of a "stockade wall" of standard steel pipe was considered. This basic design enables the use of standard fabricated elements that can be selected from a wide range of available sizes and wall thicknesses. The steps followed in this analysis were:

Examine the Reynolds number and drag forces for flow around submerged smooth and roughened cylinders, survey available ocean data for information regarding ocean currents, model several typical depth distributions of ocean currents that the pipe might encounter, calculate static bending moments and examine dynamic characteristics and constraints, forces, moments, and deflection for various pipe models with locked and sliding members; calculate stress in a stockade pipe both with sliding members and with locked members, find buckling modes, examine possible failure mechanisms and instabilities, calculate stiffener requirements, heat transfer, and leakage flow; estimate effects of various buoyancy conditions of the pipe, propose a general hull juncture system, evaluate total pipe and installation costs, and describe installation procedures; examine the range of pipe sizes that are reasonable for ocean thermal power plants, suggest a continuing program to construct and test a geometric model, and/or develop a more sophisticated analytical model of the pipe.

PUBLICATIONS AVAILABLE

See Bibliography Reference No. 86

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering/Intake Screens

CONTRACTOR & ADDRESS

Oregon State University
Department of Mechanical Engineering
Corvallis, Oregon 97331

CONTRACT NO.

ERDA E(45-1)-2227

PERIOD OF PERFORMANCE

Sept. 15, 1976 to Sept. 14, 1977

PRINCIPAL INVESTIGATOR

John H. Nath
(503) 754-2354

FUNDING

$55,400

TITLE

Biological and hydrodynamic influences on the screens of OTEC intake systems

SUMMARY

This study will provide basic information on biologic and hydrodynamic factors that will influence the design of screens at the intake structures of an OTEC plant. To accomplish this, the contractor will gather and summarize available knowledge of the biota of the ocean environments for proposed OTEC sitings, assess and document hydraulic energy losses and other costs of candidate designs of screens which will exclude certain biota, develop first order design criteria for the configuration of cold and warm water intake screens, and design an experiment for sampling the biota at deep depths.

PUBLICATIONS AVAILABLE

BIBLIOGRAPHY

Introduction

This bibliography contains information pertinent to the projects in this report. The information dates back as far as useful references could be obtained, and is current through March 1976. All references are listed under 1) the page reference number of the project summarized, 2) author's name (if stated in reference), 3) title of article, 4) author's organizational affiliation, 5) title of publication, and 6) report number. A listing may contain one of the following abbreviations as to availability:

Dep. ERDA reports so designated are maintained in microform at the organizations listed on the inside back cover.

GPO For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

NTIS For sale by the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. Microfiche copy of each separately bound document can be purchased for $2.25. Reports issued by organizations outside the United States will be sold by NTIS only to purchasers within the United States.

TIC Available from the USERDA Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

NSF On file at the RANN Library, National Science Foundation, 1800 G Street, N.W., Washington, D.C. 20550.

19. Adams, C.R., *Preliminary Analysis of Ocean Thermal Power Plant Architecture and Statistics* (Massachusetts Univ., Amherst, MA), June 1973, 16p. (NSF/RA/N-73-096) NTIS.

19. Ambs, L.L.; Marshall, J., *Ocean Thermal Difference Power Plant Turbine Design* (Massachusetts Univ., Amherst, MA), Nov. 1973, 32p. (NP-20462) NSF/RANN.

19. Anderson, J.H., *Heat Exchangers for Sea Solar Power Plants* (Massachusetts Univ., Amherst, MA), Sept. 1973, 45p. (NSF/RA/N-73-137).

19. Anderson, J.H., *Turbine Design, Sea Solar Power Plants* (Massachusetts Univ., Amherst, MA), June 1973, 22p. (NSF/RA/N-73-055) NTIS.

19. Anderson, J.H.; Anderson, J.H., Jr., *Summary of The Anderson and Anderson Analysis of The Sea Solar Power Process, 1964 to 1972* (Massachusetts Univ., Amherst, MA), March 1973, 81p. (NSF/RA/N-73-091) NTIS.

19. Anderson, J.H., *Working Fluids For The Sea Solar Power Process* (Massachusetts Univ., Amherst, MA), May 1973, 24p. (NSF/RA/N-73-092) NTIS.

19. Anderson, J.H., *Research Applied to Ocean Sited Power Plants. Annual Progress Report, Jan. 1 – Dec. 31, 1973* (Massachusetts Univ., Amherst, MA), Jan. 25, 1974, 70p. (PB-228067) NTIS. $3.75; $1.45 (mf).

19. Anderson, J.H., *Research Applied to Ocean Sited Power Plants. Semi-Annual Progress Report, Jan. 1 – June 30, 1973* (Massachusetts Univ., Amherst, MA), July 31, 1973, 66p. (PB-228070) NTIS. $3.75; $1.45 (mf).

19. Boot, J.; McGowan, J.G., *Preliminary Investigation of an Open Cycle Ocean Thermal Difference Power Plant Design* (Massachusetts Univ., Amherst, MA), Aug. 1973, 47p. (PB-239393) NTIS. $3.75.

19. Boot, J.; McGowan, J.G., *Preliminary Investigation of an Open Cycle Open Thermal Difference Power Plant Design* (Massachusetts Univ., Amherst, MA), Aug. 1973, 45p. (NSF/RA/N-73-136).

19. Boot, J.L.; McGowan, J.G., *Feasibility Study of a 100 Megawatt Open Cycle Ocean Thermal Difference Power Plant* (Massachusetts Univ., Amherst, MA), Aug. 1974, 100p. (NP-20465) NSF/RANN.

19. Boot, J.L.; McGowan, J.G., *Feasibility Study of a 100 Megawatt Open Cycle Ocean Thermal Difference Power Plant* (Massachusetts Univ., Amherst, MA), Aug. 1974, Contract GI-34979, 67p. (NSF/RA/N-74-109).

19. Cloutier, P.D., *Analysis of the Cooling Water Pumping Power Requirements of the Ocean Thermal Gradient Electricity Generating System (OTGEGS)* (Massachusetts Univ., Amherst, MA), Dec. 1972, 43p. (NP-20464) NSF/RANN.

19. Cloutier, P.D., *Preliminary Technology Assessment of Ocean Thermal Gradient Energy Generation* (Massachusetts Univ., Amherst, MA), July 1974, 209p. (NP-20461) NSF/RANN.

19. Connell, J.W.; McGowan, J.G., *Condenser Requirements for an Ocean Thermal Gradient Power Plant* (Massachusetts Univ., Amherst, MA), Dept. of Mechanical Engineering, June 1973, 8p. (NSF/RA/N-73-100) NTIS.

19. Connell, J.W.; McGowan, J.G., *Initial Investigation of Boiler and Condenser Tube Designs* (Massachusetts Univ., Amherst, MA, Dept. of Mechanical Engineering), June 1973, 35p. (NSF/RA/N-73-054) NTIS.

19. Dzialo, F.J.; Stoddard, F.S., *Plane Strain Solutions For Thick Cylindrical Submersible Shells* (Massachusetts Univ., Amherst, MA), June 1973, 20p. (NSF/RA/N-73-093) NTIS.

19. Goss, W.P.; Heronemus, W.E.; Mangarella, P.A.; McGowan, J.G., *Summary of University of Massachusetts Research on Gulf Stream Based Thermal Power Plants* (Univ. of Massachusetts, Amherst, MA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975), (APL/JHU-SR–75-2, pp. 51-63).

19. Heronemus, W.E.; Adams, C.R.; Ambs, L.L.; Chajes, A.; Dzialo, F.J.; Kirchloff, R.H.; Mangarella, P.A.; McGowan, J.G.; McKibbin, W.L.; Zoltners, A.; Lessard, R.D., *Technical and Economic Feasibility of the Ocean Thermal Differences Process as a Solar-Driven Energy Process. First Quarterly Progress Report, January 1, 1974 – March 31, 1974* (Massachusetts Univ., Amherst, MA), April 30, 1974, 57p. (NSF/RA/N-74-160) NTIS.

19. Heronemus, W.E.; McGowan, J.G., *Ocean Thermal Power and Windpower Systems: Natural Solar Energy Conversion for Near-Term Impact on World Energy Markets* (Massachusetts Univ., Amherst, MA). Adv. Astronaut. Sci.; 35: Suppl. 491-507 (1975). Energy Symposium of the 140th Annual Meeting of the American Association for the Advancement of Science; San Francisco, CA (Feb. 25, 1974).

19. Heronemus, W.E., *Research Applied to Ocean Sited Power Plants. Annual Progress Report, Jan. 1 – Dec. 31, 1973* (Massachusetts Univ., Amherst, MA), Jan. 25, 1975, 74p. (NSF/RA/N-74-002) NTIS.

19. Heronemus, W.E.; McGowan, J.G., *Some Views on Solar Sea Power Plants. A Project Sponsored by NSF-RANN* (Massachusetts Univ., Amherst, MA), June 1975. Proceedings, Solar Sea Plant Conference and Workshop; Pittsburgh, Pennsylvania (June 27, 1973). (PB-228066, pp. 21-59) NTIS, $6.95.

19. Heronemus, W.E., *Technical and Economic Feasibility of the Ocean Thermal Differences Process. Third Quarter Progress Report, July 1, 1974 – September 30, 1974* (Massachusetts Univ., Amherst, MA), Dec. 1, 1974, 108p. (NP-20463) NSF/RANN.

19. Heronemus, W.E., *Technical and Economic Feasibility of the Ocean Thermal Differences Process as a Solar-Driven Energy Process. Semi-Annual Progress Report, Jan. 1, 1974 – June 1974* (Massachusetts Univ., Amherst, MA) July 31, 1974, 52p. (PB-236422) NTIS, $3.75.

19. Heronemus, W.E., *Research Applied to Ocean Sited Power Plants. First Quarter Progress Report, December 31, 1972 – March 31, 1973* (Massachusetts Univ., Amherst, MA), 1973, 61p. (NP-20475) NSF/RANN.

19. Heronemus, W.E., *Proposed Ocean Thermal Energy Conversion Systems Program Plan (The OTECS Plan)* (Massachusetts Univ., Amherst, MA), March 1975, 36p. (TID-26850) Dep. NTIS, $5.00.

19. Kirchhoff, R.H.; McGowan, J.G.; Connell, J.W.; Seluk, D., *Hot Side Heat Exchanger For an Ocean Thermal Difference Power Plant* (Mechanical Engineering Department, University of Massachusetts, Amherst, MA), pp. 354-361 of 9th Intersociety Energy Conversion Engineering Conference; San Francisco, CA, Aug. 26-30, 1974. New York; American Society of Mechanical Engineers (1974).

19. Mangarella, P.A., *Analysis of The Fluid Motion Into The Condenser Intake of a 400 MWe Ocean Thermal Difference Power Plant* (Massachusetts Univ., Amherst, MA), March 1975, 25p. (TID-26964) Dep. NTIS, $4.50.

19. Marshall, J.; Ambs, L, *Evaluation of The Major and Support Fluid System Necessary for The Operation of a Rankine Cycle Ocean Thermal Difference Machine* (Massachusetts Univ., Amherst, MA), Nov. 1974, 42p. (NP-20460) NSF/RANN.

19. McGowan, J.G.; Heronemus, W.E.; Connell, J.W.; Cloutier, P.D., *Ocean Thermal Difference Power Plant Design* (Massachusetts Univ., Amherst, MA), June 1973, 22p. (NSF/RA/N-73-094) NTIS.

19. McGowan, J.G.; Connell, J.W.; Braren, R., *Variations in Heat Exchanger Design for Ocean Thermal Difference Power Plants* (Massachusetts Univ., Amherst, MA), Aug. 1974, 49p. (NSF/RA/N-75-110) NTIS.

19. Seluk, D.; Kirschhoff, R.H., *Hot Water Hydraulics of The Gulf Stream Sited OTGM* (Massachusetts Univ., Amherst, MA), March 1975, 75p. (TID-26853) Dep. NTIS, $6.75.

19. Seluk, D.; Kirschhoff, R.H., *Hot Water Hydraulics of The Gulf Stream Sited OTGM* (Massachusetts Univ., Amherst, MA), March 1975, 68p. (NSF/RA/N-75-027) NTIS.

19. VanDusen, E.; Mangarella, P.A., *Analysis of The Thermal and Nutrient Properties of The Condenser Discharge Plume Created By an Ocean Thermal Difference Power Plant* (Massachusetts Univ., Amherst, MA), Oct. 1974, 60p. (NP-20474) NSF/RANN.

19. *Technical and Economic Feasibility of The Ocean Thermal Differences Process. Progress Report for Period January 1, 1974 – January 1, 1975* (Massachusetts Univ., Amherst, MA), Feb. 1, 1975, 106p. (TID-26790) Dep. NTIS, $8.50.

20. Finzi, L.A., *Major Electric Equipment Cost Figures for Solar Sea Power Plants* (Carnegie-Mellon Univ., Pittsburgh, PA), Oct. 1974, 46p. (NP-20466) NSF/RANN.

20. Kriebel, C.H., *Preliminary Technology Assessment of Solar Power Plants for Ocean Thermal Energy Conversion* (Carnegie-Mellon Univ., Pittsburgh, PA), Nov. 1974, 72p. (NP-20458) NSF.

20. Lavi, A., *Solar Sea Power Plants, Cost and Economics* (Carnegie-Mellon Univ., Pittsburgh, PA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 64-71).

20. Lavi, A., *Solar Sea Power Project. Progress Report January 1, 1975 – August 31, 1975* (Carnegie-Mellon Univ., Pittsburgh, PA), Aug. 31, 1975, 176p. (NSF/RANN/SE/GI–39114/PR/75/1) Dep. NTIS, $8.50.

20. Lavi, A., *Solar Sea Power Project. Final Report, June 1, 1973 – December 31, 1974* (Carnegie-Mellon Univ., Pittsburgh, PA), Jan. 31, 1975, 131p. (NP-20454) Carnegie-Mellon Univ., Pittsburgh, PA.

20. Lavi, A. (ed.), *Proceedings, Solar Sea Power Plant Conference and Workshop* (Carnegie-Mellon University, Pittsburgh, PA), June 1973, 287p. Solar Sea Power Conference and Workshop; Pittsburgh, PA (June 27, 1973) (PB-228066) NTIS, $6.75.

20. Lavi, A.; Zener, C., *Plumbing The Ocean Depths: New Source of Power* (Carnegie-Mellon Univ., Pittsburgh, PA), IEEE Spectrum; 10: No. 10, 22-7 (Oct. 1973).

20. Lavi, A.; Zener, C., *Thermal Energy From Oceanic Deepness* (Carnegie-Mellon Univ., Pittsburgh, PA) Electrotechnica; 61: No. 2, 95-100 (February 1974). (In Italian).

20. Witaker, W.L.; Krokosky, E.M., *Guyed Column Structure for The Cold-Water Intake Pipe for Solar Sea Power Plants* (Carnegie-Mellon Univ., Pittsburgh, PA), Oct. 1974, 66p. (NP-20467) NSF/RANN.

20. Zener, C.; Lavi, A.; Wu, C.C., *Solar Sea Power. First Quarterly Progress Report, June 1 – September 1973* (Carnegie-Mellon Univ., Pittsburgh, PA), Oct. 11, 1973, 140p. (PB-228069) NTIS, $4.75.

20. Zener, C.; Rothfus, R.R.; McMichael, F.C.; Kriebel, C.; Lavi, A.; Krokosky, E.; Wu, C.C., *Solar Sea Power, Third Quarterly Progress Report, February 1, 1974 – April 30, 1974* (Carnegie-Mellon Univ., Pittsburgh, PA (USA)), Apr. 30, 1974, 83p. (PB-235469) NTIS, $4.75.

20. Zener, C., *Solar Sea Power* (Carnegie-Mellon Univ., Pittsburgh, PA). AIP (Am. Inst. Physc.) Topical Conference on Energy; Chicago, Illinois (Feb. 4, 1974); No. 19, 412-426 (1974).

20. Zener, C., *Solar Sea Power. Fifth Quarterly Progress Report, July 1, 1974 – September 30, 1974* (Carnegie-Mellon Univ., Pittsburgh, PA), Oct. 31, 1974, 15p. (NP-20472) NSF/RANN.

20. Zener, C., *Solar Sea Power. Annual Progress Report, April 1, 1974 – June 30, 1974* (Carnegie-Mellon Univ., Pittsburgh, PA), July 31, 1974, 138p. (NSF/RANN/SE/GI-39114/PR/74/4).

20. Zener, C.; Lavi, A., *Drainage Systems for Condensation* (Carnegie-Mellon Univ., Pittsburgh, PA), 1973, 38p. (PB-227967) NTIS, $3.25; $1.45 (mf).

20. Zener, C.; Lavi, A.; Rothfus, R.; McMichael, F.; Wu, C.C., *Solar Sea Power. Semiannual Progress Report, November 1, 1973 – January 31, 1974* (Carnegie-Mellon Univ., Pittsburgh, PA), Jan. 25, 1974, 113p. (PB-228068).

20. Zener, C.; Dykstro, L.J.; Rothfus, R.R.; Lavi, A.; Krokosky, E.; Kriebel, C.; McMichael, F.C.; Wu, C.C., *Solar Sea Power. Annual Progress Report Covering The Period April 1, 1973 – June 30, 1974* (Carnegie-Mellon Univ., Pittsburgh, PA), July 31, 1974, 130p. (PB-236997) NTIS, $5.75.

20. Zener, C.; Lavi, A., *Drainage Systems for Condensation* (Carnegie-Mellon Univ., Pittsburgh, PA), ASME meeting; (Nov. 11-15, 1973). (ASME Paper 73-WA/Sol-2, New York), ASME (1973), 7p.

20. Zener, C., *Solar Sea Power* (Carnegie-Mellon Univ., Pittsburgh, PA). Physics Today; 26: No. 1, 48-53 (Jan. 1973).

20. Zener, C.; Lavi, A., *Drainage Systems for Condensation* (Carnegie-Mellon Univ., Pittsburgh, PA). J. Eng. Power; 96: No. 3, 209-14 (July 1974). (73-WA/SOL-2).

20. *Solar Sea Power Plant Conference and Workshop at Carnegie-Mellon University, Schenley Park, Pittsburgh, PA. June 27-28, 1973.* Washington, D.C.; National Science Foundation (1973).

22. Trimble, L.C., *Ocean Thermal Energy Conversion System Study Report* (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975). (APL/JHU-SR–75-2, pp. 3-21).

22. *Ocean Thermal Energy Conversion (OTEC) Power Plant Technical and Economic Feasibility. Vol. II. Supporting Data* (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA), Apr. 12, 1975, 818p. (LMSC-D–056566) (Vol. 2). (NSF/RANN/SE/GI-C–937/FR/75/1 (Vol. 2)).

22. *Ocean Thermal Energy Conversion (OTEC) Power Plant Technical and Economic Feasibility. Vol. 1. Technical Report* (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA), Apr. 12, 1975, 194p. (LMSC-D–056566) (Vol. 1). (NSF/RANN/SEC/GI-C–937/FR/1 (Vol. 1)).

23. *Ocean Thermal Energy Conversion. Research on an Engineering Evaluation and Test Program. Volume 1. Executive Summary. Final Report* (TRW Systems Group, Redondo Beach, CA), June 1975, 83p. (SAN-1089-TI-PI) Dep. NTIS, $7.25.

23. *Ocean Thermal Energy Conversion. Research on an Engineering Evaluation and Test Program. Volume 2. Evaluation of Prior Work; Subsystems and Components. Final Report* (TRW Systems Group, Redondo Beach, CA), June 1975, 167p. (SAN-1089-TI-P2) Dep. NTIS, $11.50.

23. Douglass, R.H., *Ocean Thermal Energy Conversion: An Engineering Evaluation* (TRW Inc., Redondo Beach, CA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975).

23. *Ocean Thermal Energy Conversion. Research on an Engineering Evaluation and Test Program. Volume 3. Baseline System Concept. Final Report* (TRW Systems Group, Redondo Beach, CA), June 1975, 198p. (SAN-1089-TI-P3) Dep. NTIS, $13.00.

23. *Ocean Thermal Energy Conversion. Research on an Engineering Evaluation and Test Program. Volume 4. Test Program Plan. Final Report* (TRW Systems Group, Redondo Beach, CA), June 1975, 47p. (SAN-1089-TI-P2) Dep. NTIS, $5.50.

23. *Ocean Thermal Energy Conversion. Research on an Engineering Evaluation and Test Program. Volume 5. Appendices. Final Report* (TRW Systems Group, Redondo Beach, CA), June 1975, 337p. (SAN-1089-TI-P5) Dep. NTIS, $20.00.

25. Cohen, R.; Avery, W.; Heronemus, W.; Lavi, A.; Anderson, J.H.; Douglass, R.; Trimble, L., *Panel Discussion of Issues Raised by System Study Reports.* Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 41-44).

25. Cohen, R., *OTEC Program Overview* (Energy Research and Development Administration, Washington, D.C.), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 47-50).

25. Dugger, G.L. (ed.), *Proceedings, Third Workshop on Ocean Thermal Energy Conversion (OTEC), Houston, Texas, May 8-10, 1975.* Aug. 1975, 241p. Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2) Dep. NTIS, $9.00.

25. Olsen, H.L.; Dugger, G.L.; Shippen, W.B.; Avery, W.H., *Selection of a Working Medium for The Solar Sea Power Plant* (Applied Physics Laboratory, Johns Hopkins University, Laurel, MD), 1973. Proceedings, Solar Sea Power Plant Conference Workshop, Pittsburgh, PA (June 27, 1973). (PB-228066, pp. 185-204) NTIS, $6.75.

25. Olsen, H.L.; Dugger, G.L.; Shippen, W.B.; Avery, W.H., *Preliminary Considerations for The Selection of a Working Medium for The Solar Sea Power Plant* (Applied Physics Laboratory, Johns Hopkins University, Laurel, MD), June 1973. Proceedings, Solar Sea Power Plant Conference and Workshop; Pittsburgh, PA (June 27, 1973) (PB-228066, pp. 185-204) NTIS, $6.75.

25. Rabenhorst, D.W.; Dugger, G.L., *Superflywheel for Storing Energy From OTEC Plants* (Applied Physics Laboratory, Johns Hopkins Univ., Laurel, MD), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 116-120).

25. *Anderson's Operating Model of The Ocean Thermal Energy Conversion Principle. Aug. 1975.* Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. ix).

27. Anderson, J.H., *To Design, Construct, and Test a Model Sea Solar Power Plant. Annual Progress Report, June 1, 1974 – December 12, 1974* (Sea Solar Power, Inc., York, PA), Jan. 24, 1975, 21p. (NSF-RANN/SE/GI-44213/PR/75/4) Dep. NTIS, $4.25.

27. Anderson, J.H., *Turbines for Sea Solar Power Plants* (Sea Solar Power, Inc., York, PA), June 1973. Proceedings, Solar Sea Plant Conference and Workshop; Pittsburgh, PA (June 27, 1973). (PB-228066, pp. 126-52) NTIS, $6.75.

27. Veziroglu, T.N. (ed.), *Sea Thermal Power as a Hydrogen and Methanol Generator* (University of Miami, FL), pp. 197-207 of Hydrogen Energy, Part A. New York; Plenum Publishing Corp. (1975). Hydrogen Economy, Miami Energy Conference; Miami Beach, Florida (March 18, 1974).

34. *Potential of Accelerating Commercialization of Ocean Thermal Energy Conversion (OTEC)* (Lockheed Missiles & Space Co., Inc., Sunnyvale, CA 94088), October 1975 (LMSC/D458893).

35. Dugger, G.L.; Olsen, H.L.; Shippen, W.B.; Francis, E.J.; Avery, W.H., *Tropical Ocean Thermal Power Plants Producing Ammonia or Other Products* (Applied Physics Laboratory, Johns Hopkins Univ., Laurel, MD), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 106-115).

35. Dugger, G.L., *Maritime and Construction Aspects of OTEC Plant-Ships* (Applied Physics Laboratory, Johns Hopkins University, Laurel, MD), April 1976, Executive Summary (APL/JHU-SR–76-1A) (PB-255639-AS) NTIS.

35. Dugger, G.L., *Maritime and Construction Aspects of OTEC Plant-Ships* (Applied Physics Laboratory, Johns Hopkins University, Laurel, MD), April 1976, Detailed Report (APL/JHU-SR–76-1B) (PB-257444-LL) NTIS.

36. Gregory, D.P.; Biederman, N.P.; *Optimization Study of Ocean Thermal Energy Delivery Systems Based on Chemical-Energy Carriers* (Inst. of Gas Tech., Chicago), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 121-124).

38. Hornburg, C.D.; Lindal, D.; El-Ramly, N., *Preliminary Research on an Ocean Energy Industrial Complex* (DSS Engineers, Inc., Ft. Lauderdale, FL), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 125-127).

41. Bretschneider, C.L., *Operational Sea State and Design Wave Criteria, A Generalized Study for OTEC* (Univ. of Hawaii, Honolulu, HI), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 87-91).

41. Bretschneider, C.L., *OPSES-DEWAC Operational Sea and Design Wave Criteria for OTEC* (Univ. of Hawaii, Honolulu, HI), June 30, 1976. Report 13-6, Zone 17, South China Sea; Zone 18, Philippine Sea; and Zone 19, Western Pacific Ocean.

41. Bretschneider, C.L., *OPSES-DEWAC Operational Sea and Design Wave Criteria for OTEC* (Univ. of Hawaii, Honolulu, HI), June 30, 1976. Report 13-7, Zone 29, Eastern Indian Ocean; Zone 30, Java and Banda Seas; Zone 31, Timor and Arafura Seas; Zone 32, Coral Sea and Fiji Basin.

41. Bretschneider, C.L., *OPSES-DEWAC Operational Sea and Design Wave Criteria for OTEC* (Univ. of Hawaii, Honolulu, HI), August 10, 1976, Final Report 13-F-I, Volume I.

44. Piacsek, S.A., *Thermocline Perturbations and Available Temperature Contrast for Ocean Thermal Power Plants* (Naval Research Lab., Washington, D.C.), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 176-178).

47. Bathen, K.H., *An Evaluation of Oceanographic and Socio-Economic Aspects of a Nearshore Ocean Thermal Energy Conversion Pilot Plant in Subtropical Hawaiian Waters* (Univ. of Hawaii, Honolulu, HI), 1975. vp. (NSF/RA/N-75-028) NTIS.

47. Bathen, K.H., *Oceanographic and Socio-Economic Aspects of an Ocean Thermal Energy Conversion Pilot Plant in Subtropical Hawaiian Waters* (Univ. of Hawaii, Honolulu, HI), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 162-171).

48. Atwood, D.K., *Ocean Thermal Energy Conversion: A Case Study of Resource Assessment and Environmental Impact Using a Proposed Puerto Rico Site* (Univ. of Puerto Rico, Mayagüez, PR), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-1, pp. 172-173).

49. Wolff, P.M., *OTEC Plan for Resource and Environmental Studies* (Ocean Data Systems, Inc., Monterey, CA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 174-175).

53. Rothfus, R.R., *Concurrent Studies of Enhanced Heat Transfer and Materials for Ocean Thermal Exchangers* (Carnegie-Mellon Univ., Pittsburgh, PA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 145-146).

56. Sabin, C.M.; Poppendieck, H.F.; Sellers, A.J.: *Nucleating Vaporization and Extended Surface Heat Transfer at Low Temperature Difference* (Geoscience Ltd., Solana Beach, CA), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 143-144).

57. Czikk, A.M.; Fenner, G.W.; Notaro, F.; Zawierucha, R.; McLaughlin, D., *Ocean Thermal Power Plant Heat Exchangers* (Union Carbide Corp., Tonawanda, N.Y.), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 133-137).

62. Suratt, W.B.; Hart, G.K.; Sieder, E.N., *Plastic Heat Exchangers for Ocean Thermal Energy Conversion* (DSS Engineers, Inc., Ft. Lauderdale, FL), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 138-142).

64. Iqbal, K.Z.; Starling, K.E., *Potential Advantages of Mixtures as Working Fluids in The OTEC Cycles* (University of Oklahoma, Norman), Aug. 1975. Proceedings. Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 147-150).

65. Johnson, D.E., *Environmental Energy Sources: Their Use and Storage* (Sea Motive, Inc., Tempe, AZ), pp. 6.1-6.17 of Energy, Environment, and Engineering. Stillwater, OK; Oklahoma State University (1973). Proceedings on Frontiers of Power Technology; Stillwater, Oklahoma, (Oct. 10, 1973).

66. Zener, C.; Fetkovich, J., *Foam Solar Sea Power Plant* (Carnegie-Mellon Univ., Pittsburgh, PA). Science; 189: No. 4199, 294-295 (July 25, 1975).

68. Winer, B.N.; *Electrical Energy Transmission From Ocean Thermal Power Plants* (Arthur D. Little, Inc., Cambridge, MA), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 103-105).

70. Fetkovich, J.G., *Study of Fouling and Corrosion Problems in a Solar Sea Power Plant* (Carnegie-Mellon Univ., Pittsburgh, PA), August 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 155-156).

70. Rothfus, R.R., *Effects of Fluid Flow on Heat Exchanger Concepts* (Carnegie-Mellon Univ., Pittsburgh, PA), September 5, 1975, 59p. (NSF/RANN/SE/GI–39114/TR/75/1) NTIS, $5.50.

74. Jones, P.E.; Ostrozynski, R.L., *Prevention of Biofouling of Heat Transfer Surfaces of Ocean Thermal Energy Converters* (Allied Chemical Corp., Buffalo, N.Y.), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 151-154).

77. Knight, H.G.; Nyhart, J.D.; Stein, R.E., *Legal Considerations of OTEC: Some Initial Views* (American Society of International Law, Washington, D.C.), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 179-181).

79. Chen, W.-F., *Reinforced Concrete Constitutive Relations for Application to OTEC Plant Structures* (Lehigh Univ., Bethlehem, PA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975).

80. Haynes, H.H., *Feasibility of Submerged Concrete Structures for OTEC Power Plants* (Naval Construction Battalion Center, Port Hueneme, CA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 98).

81. Valent, P.J.; Taylor, R.J.; Lee, H.J.; and Rail, R.D., *State of The Art in High Capacity, Deep Water Anchor Systems* (Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, CA), January 1976, Technical Memorandum No. M-42-76-1.

82. Little, T.E., *Deep Water Pipe and Mooring Design Study* (Westinghouse Electric Corp., Annapolis, MD), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975).

84. Barr, R.A., *Evaluation of Platform Designs for Ocean Thermal Power Plants* (Hydronautics, Inc., Laurel, MD), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975).

84. Brown, C.E.; Wechsler, L., *Engineering an Open Cycle Power Plant for Extracting Solar Energy From The Sea* (Hydronautics, Inc.). pp. 111-126 of Proceedings of 7th Annual Offshore Technology Conference, Houston, TX (May 5-8, 1975), Volume 2. Dallas, TX; Offshore Technol. Conf. (1975).

84. Brown, C.E.; Wechsler, L., *Engineering an Open Cycle Power Plant for Extracting Solar Energy From The Sea* (Hydronautics, Inc., Laurel, MD), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 75-78).

86. Anderson, J.H.; Anderson, J.H. Jr., *Cold-Water Pipe: A Design Feasibility Study* (Sea Solar Power, Inc., York, PA), Aug. 1975. Proceedings, Third Workshop on OTEC; Houston, Texas: Applied Physics Laboratory, Johns Hopkins University (May 8, 1975) (APL/JHU-SR–75-2, pp. 92).

86. Anderson, J.H., *Design of Cold-Water Pipe for Sea Thermal Power Plants. Progress Report, May 1, 1975 – September 15, 1975.* (Sea Solar Power, Inc., York, PA), Sept. 1975, 43p. (COO-2691-1) Dep. NTIS, $4.00.

INDEX

INDEX (Continued)

INDEX (Continued)